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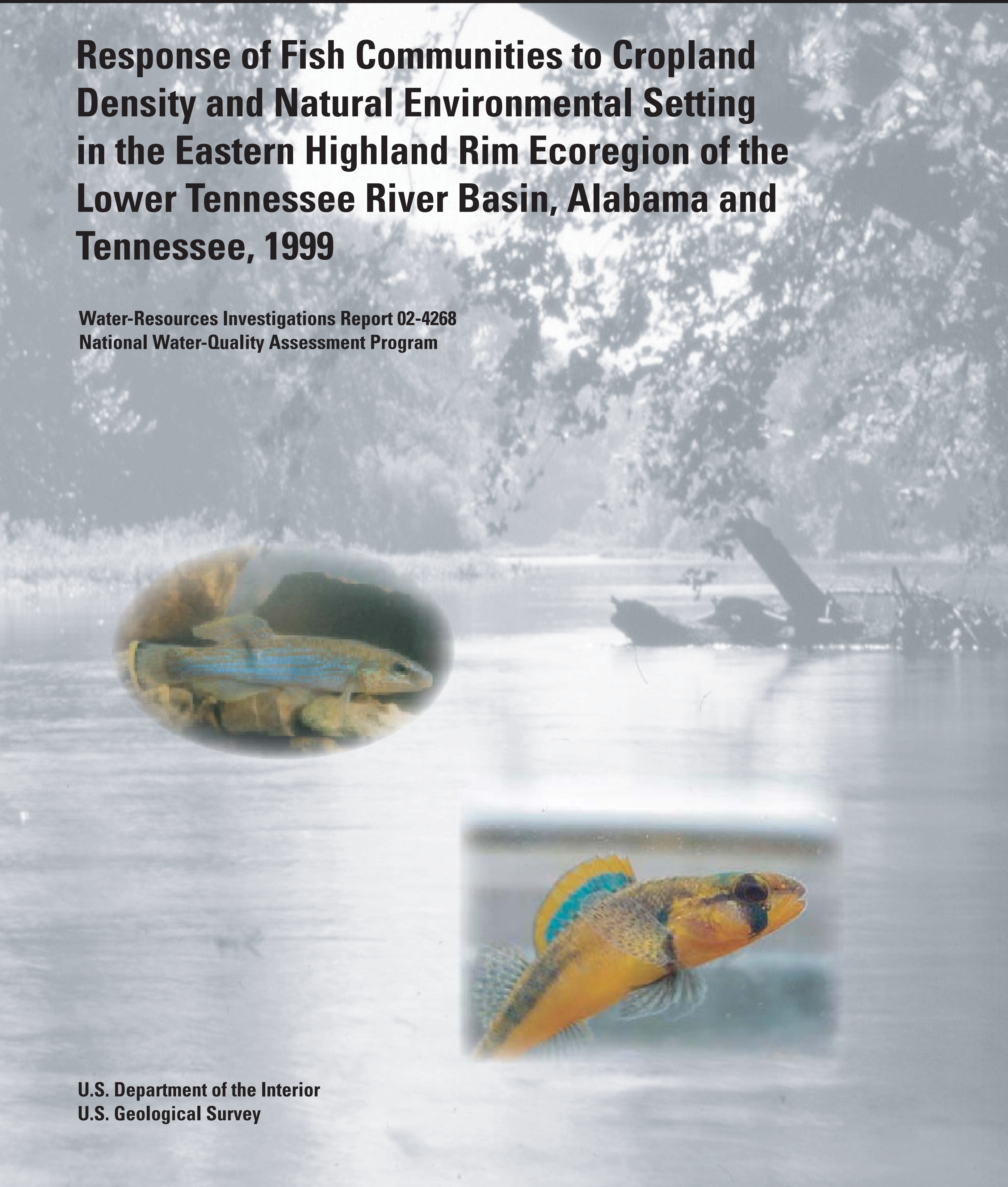
Response of Fish Communities to Cropland Density and Natural Environmental Setting in the Eastern Highland Rim Ecoregion of the Lower Tennessee River Basin, Alabama and Tennessee, 1999



Water-Resources Investigations Report 02-4268
National Water-Quality Assessment Program

U.S. Department of the Interior
U.S. Geological Survey

Cover photographs: Background photograph is the Duck River at Osteen Bend (river mile 173.1), Marshall County, Tennessee (Photograph by Rodney Knight, USGS). Left photo is the Northern studfish—*Fundulus catenatus* (Photograph by Rodney Knight, USGS). Right photo is the Slackwater Darter—*Etheostoma boschungi* (Photograph by J.R. Shute, Conservation Fisheries, Inc. Used with permission.)

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By Jeffrey R. Powell

U.S. GEOLOGICAL SURVEY

Water-Resources Investigations Report 02-4268

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More information about the National Water-Quality Assessment (NAWQA) Program is available via the World Wide Web at: http://water.usgs.gov/nawqa/naqwa_home.html

FOREWORD

The U.S. Geological Survey (USGS) is committed to serve the Nation with accurate and timely scientific information that helps enhance and protect the overall quality of life, and facilitates effective management of water, biological, energy, and mineral resources. Information on the quality of the Nation's water resources is of critical interest to the USGS because it is so integrally linked to the long-term availability of water that is clean and safe for drinking and recreation and that is suitable for industry, irrigation, and habitat for fish and wildlife. Escalating population growth and increasing demands for the multiple water uses make water availability, now measured in terms of quantity *and* quality, even more critical to the long-term sustainability of our communities and ecosystems.

The USGS implemented the National Water-Quality Assessment (NAWQA) Program to support national, regional, and local information needs and decisions related to water-quality management and policy. Shaped by and coordinated with ongoing efforts of other Federal, State, and local agencies, the NAWQA Program is designed to answer: What is the condition of our Nation's streams and ground water? How are the conditions changing over time? How do natural features and human activities affect the quality of streams and ground water, and where are those effects most pronounced? By combining information on water chemistry, physical characteristics, stream habitat, and aquatic life, the NAWQA Program aims to provide science-based insights for current and emerging water issues and priorities. NAWQA results can contribute to informed decisions that result in practical and effective water-resource management and strategies that protect and restore water quality.

Since 1991, the NAWQA Program has implemented interdisciplinary assessments in more than 50 of the Nation's most important river basins and aquifers, referred to as Study Units. Collectively, these Study Units account for more than 60 percent of the overall water use and population served by public water supply, and are representative of the Nation's major hydrologic landscapes, priority ecological resources, and agricultural, urban, and natural sources of contamination.

Each assessment is guided by a nationally consistent study design and methods of sampling and analysis. The assessments thereby build local knowledge about water-quality issues and trends in a particular stream or aquifer while providing an understanding of how and why water quality varies regionally and nationally. The consistent, multi-scale approach helps to determine if certain types of water-quality issues are isolated or pervasive, and allows direct comparisons of how human activities and natural processes affect water quality and ecological health in the Nation's diverse geographic and environmental settings. Comprehensive assessments on pesticides, nutrients, volatile organic compounds, trace metals, and aquatic ecology are developed at the national scale through comparative analysis of the Study-Unit findings.

The USGS places high value on the communication and dissemination of credible, timely, and relevant science so that the most recent and available knowledge about water resources can be applied in management and policy decisions. We hope this NAWQA publication will provide you the needed insights and information to meet your needs, and thereby foster increased awareness and involvement in the protection and restoration of our Nation's waters.

The NAWQA Program recognizes that a national assessment by a single program cannot address all water-resource issues of interest. External coordination at all levels is critical for a fully integrated understanding of watersheds and for cost-effective management, regulation, and conservation of our Nation's water resources. The Program, therefore, depends extensively on the advice, cooperation, and information from other Federal, State, interstate, Tribal, and local agencies, non-government organizations, industry, academia, and other stakeholder groups. The assistance and suggestions of all are greatly appreciated.

Robert M. Hirsch

Robert M. Hirsch
Associate Director for Water

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CONVERSION FACTORS, DATUM, WATER-QUALITY UNITS, AND LIST OF ACRONYMS AND ABBREVIATIONS

Multiply	By	To obtain
inch (in.)	2.54	centimeter (cm)
foot (ft)	0.3048	meter (m)
mile (mi)	1.609	kilometer (km)
acre	0.4047	hectare (ha)
square mile (mi^2)	2.590	square kilometer (km^2)
cubic foot per second (ft^3/s)	0.02832	cubic meter per second (m^3/s)

Temperature in degrees Fahrenheit (°F) may be converted to degrees Celsius (°C) as follows: °C = (°F - 32) / 1.8

Vertical coordinate information is referenced to the North American Vertical Datum of 1988 (NAVD 88).

Horizontal coordinate information is referenced to the North American Datum of 1983 (NAD 83).

Water-quality units

µg/L	micrograms per liter
mg/L	milligrams per liter
µS/cm	microsiemens per centimeter
col./100 mL	colonies per 100 milliliters

Acronyms

BSI	Bank stability index
CA	Correspondence analysis
CAFO	Confined animal feeding operations
DT	Dissected Tablelands
EDA	Exploratory data analysis
EHR	Eastern Highland Rim
ERDAS	Earth Resources Data Acquisition Services
HHL	Habitat, hydrology, and land use
IBI	Index of Biological Integrity
IGA	Indirect gradient analysis
LTEN	Lower Tennessee
MV	Moulton Valley
MVSP	Multivariate Statistical Package
NAWQA	National Water-Quality Assessment
NWQL	National Water Quality Laboratory
PCA	Principal components analysis
TVA	Tennessee Valley Authority
USGS	U.S. Geological Survey

Response of Fish Communities to Cropland Density and Natural Environmental Setting in the Eastern Highland Rim Ecoregion of the Lower Tennessee River Basin, Alabama and Tennessee, 1999

By Jeffrey R. Powell

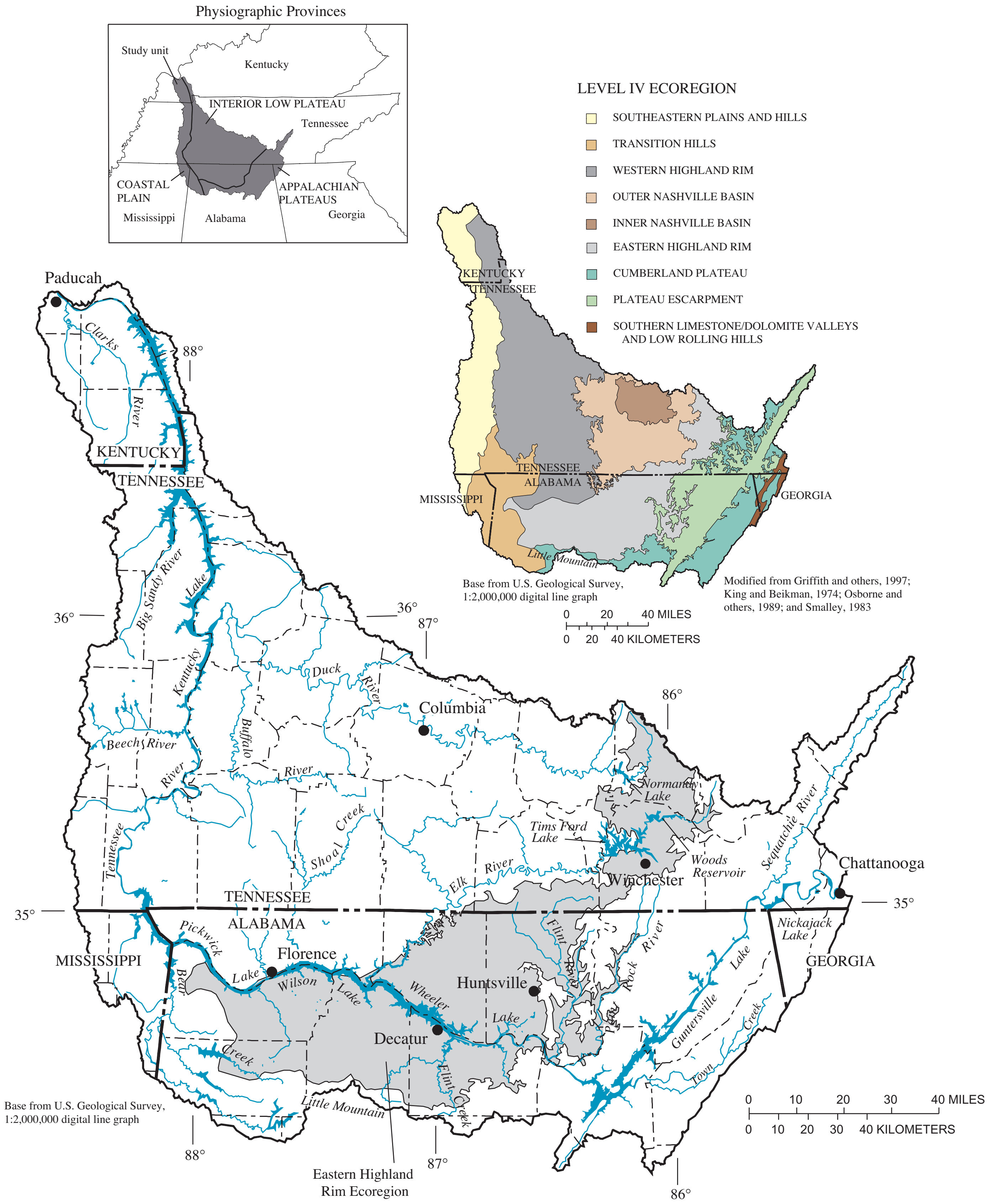
ABSTRACT

Response of fish communities to cropland density and natural environmental setting were evaluated at 20 streams in the Eastern Highland Rim Ecoregion of the lower Tennessee River Basin during the spring of 1999. Sites were selected to represent a gradient of cropland densities in basins draining about 30 to 100 square miles. Fish communities were sampled by using a combination of seining and electrofishing techniques. A total of 10,550 individual fish, representing 63 species and 15 families, were collected during the study and included the families Cyprinidae (minnows), 18 species; Percidae (perch and darters), 12 species; and Centrarchidae (sunfish), 12 species. Assessments of environmental characteristics, including instream and terrestrial data and land-cover data, were conducted for each site. Instream measurements, such as depth, velocity, substrate type, and embeddedness, were recorded at 3 points across 11 equidistant transects at each site. Terrestrial measurements, such as bank angle, canopy angle, and canopy closure percentage, were made along the stream bank and midchannel areas. Water-quality data collected included pH, dissolved oxygen, specific conductivity, water temperature, nutrients, and fecal-indicator bacteria.

Substrate embeddedness was the only variable correlated with both cropland density and fish communities (as characterized by ordination scores and several community level metrics). Multivariate and nonparametric correlation techniques were used to evaluate fish-community responses to physical and chemical factors associated with a cropland-density gradient, where the gradient was defined as the percentage of the basin in row crops. Principal component analysis and correspondence analysis suggest that the Eastern Highland Rim Ecoregion is composed of three subgroups of sites based on inherent physical and biological differences. Data for the subgroup containing the largest number of sites were then re-analyzed, revealing that several environmental variables, such as nutrient concentrations, stream gradient, bankfull width, and substrate embeddedness, were related to cropland density; however, only a subset of those variables (substrate embeddedness, elevation, and streamflow) were related to fish communities. Results from this analysis suggest that although many water-quality and habitat variables are covariant with cropland density, most of the variables do not significantly affect fish-community composition; instead, fish communities primarily respond to the cumulative effects of sedimentation.

INTRODUCTION

In 1997, the U.S. Geological Survey (USGS) began an assessment of the Lower Tennessee (LTEN) River Basin as part of the National Water-Quality Assessment (NAWQA) Program. The goals of the program are to describe the status of and trends in the Nation’s surface- and ground-water resources by developing an understanding of the factors that influence current water-quality conditions (Hirsch and others, 1988). The LTEN River Basin, one of the 59 study areas located in the conterminous United States, extends from Chattanooga, Tenn., to its confluence with the Ohio River near Paducah, Ky. (fig. 1). The LTEN River Basin has one of the most diverse fish faunas of any river system in North America, supporting approximately 193 native species (Etnier and



Base from U.S. Geological Survey, 1:2,000,000 digital line graph

Modified from Griffith and others, 1997; King and Beikman, 1974; Osborne and others, 1989; and Smalley, 1983

Base from U.S. Geological Survey, 1:2,000,000 digital line graph

Eastern Highland Rim boundaries modified from King and Beikman, 1974; Smalley, 1983; Osborne and others, 1989; and Griffith and others, 1997

Figure 1. Location of the lower Tennessee River Basin study unit, physiographic provinces, level IV ecoregions, and the Eastern Highland Rim Ecoregion.

Starnes, 1993; Mettee and others, 1996). Dams and other anthropogenic stressors contributing to water-quality impairment and habitat destruction are the greatest threats to this rich fauna (Etnier, 1997). These types of stressors not only affect aquatic inhabitants but also jeopardize domestic drinking-water supplies and the recreational value of the resource.

In Alabama and Tennessee, agriculture is the most frequently mentioned source of impairment to streams and rivers in the LTEN River Basin (Tennessee Department of Environment and Conservation, 2000; Alabama Department of Environmental Management, 2000). The constituent most frequently cited as the cause of impairment is sediment. Other causes of impairment that frequently accompany sedimentation from agricultural sources include pathogens associated with animal waste, altered channel morphology and habitat loss, nutrients that cause excessive algal growth, and chemical pollutants originating from cultivated row crops.

The emphasis on agriculture and its potential effect on rivers, streams, and biota is a growing concern nationwide. Reports from the U.S. Environmental Protection Agency list siltation from agriculture as the most important of all river pollutants—more than three times higher than forestry, mining, or urban development (Waters, 1995). Although some form of agriculture occupies nearly one-third of the surface area of the continental United States, the types of agricultural activities are variable and lead to a wide array of agricultural byproducts that have the potential to reach streams. These byproducts can vary from acute pesticide exposures to chronic erosion and sedimentation from livestock-trampled stream banks. Cooper (1993) suggests that sometimes the more subtle, chronic exposures may be as damaging as acute exposures. Although the response from acute exposures may be more noticeable at first (for example, fish kills), the results from long-term exposures may be more damaging.

One objective of the NAWQA Program is to provide an understanding of how changing land-use patterns affect the chemical, physical, and biological make-up of streams. Relating change in fish communities to chemical and physical variability is critical in understanding how streams are affected by land-use practices, such as agriculture. Although most ichthyologists accept that large-scale differences in fish distributions are controlled by natural factors, such as geology and climate, trends associated with changing land-use patterns can play a significant role in determining the types of fishes present in a particular stream. Fish communities, which are species that co-exist in the same stream, have the ability to complement both chemical and physical assessments by directly integrating water-quality effects and providing one of the few water-quality assessment methods that is sensitive to both toxicological and habitat disturbances (Cuffney and others, 1997). Gross differences in community structure within ecoregions are usually the result of localized disturbances; therefore, community level responses can be used to evaluate changing land-use patterns along gradients of intensity. This type of multidisciplinary approach is one of the basic components of the NAWQA Program.

Purpose and Scope

The purposes of this report are to identify the primary environmental characteristics that influence fish-community structure in the Eastern Highland Rim Ecoregion (EHR) of the LTEN River Basin and to determine if those characteristics are related to cropland density, which is the percentage of cropland in the contributing basin. Physical, chemical, and biological data were collected at 20 streams within the EHR in 1999. Streams were selected from the EHR, rather than from the entire LTEN River Basin, so that natural physiographic and biological differences would be minimized and sampling efforts could be concentrated in the most intensively cultivated region of the LTEN River Basin. Results from this analysis provide a framework for using fish communities as indicators of aquatic impairment, along with specific chemical and physical characteristics associated with increasing cropland.

Description of the Eastern Highland Rim Ecoregion

The LTEN River Basin covers three distinct regions: the Coastal Plain, the Interior Low Plateau, and the Appalachian Plateaus Physiographic Provinces (fig. 1). These regions are defined by their geologic, topographic, and climatic similarities (Fenneman, 1938). The Interior Low Plateau Physiographic Province is divided into sections, one of which is the Highland Rim. The Highland Rim extends west of the Cumberland escarpment, surrounds the Nashville Basin, and continues westward to the Coastal Plain region and is characterized by gently rolling hills, numerous karst features (caves, sinkholes, and springs), and chert-filled streams that dissect an old peneplain surface. The eastern side of the Highland Rim, referred to as the EHR, is recognized as one of the five level IV ecoregions of the Interior Low Plateau Physiographic Province (Griffith and others, 1997) (fig. 1).

According to Safford's (1869) description, "If one could be elevated 2,000 or 3,000 feet above Nashville, they would see, the Highland Rim, rising up first in bold walls—terrace-like—all around the Basin, and then extending off, in every direction, in great plains."

The EHR makes up about 18 percent of the overall surface area of the LTEN River Basin (Kingsbury and others, 1999). The boundaries of the EHR extend southwest into Alabama, across the Tennessee River, and include the area between Little Mountain and the western escarpment of the Cumberland Plateau Ecoregion. North of the Tennessee River, the EHR follows an arbitrary boundary along the Elk River to near Winchester, Tennessee, and then north to the southeastern border of the Outer Nashville Basin and the western slope of the Cumberland Plateau (fig. 1). Streams in the EHR commonly flow in entrenched channels characterized by broad valleys, steep side slopes, and undercut banks. These streams are continuously down-cutting and in the early stages of flood plain and terrace development (Theis, 1936). Major river basins in the EHR include the Flint River, upper Duck River, upper and southeastern drainages of the Elk River, and numerous tributaries to the main stem of the Tennessee River.

The climate and population of the EHR are typical of most regions in the southeastern United States. The climate is temperate and characterized by long, hot summers and short, mild winters with a mean annual temperature of 58 °F (National Weather Service, 2001). Total annual precipitation averages about 57 inches per year, which is distributed evenly throughout the year; however, spring and summer convective storms can deliver short intensive amounts of rainfall resulting in flash flooding. Precipitation in the form of snow rarely exceeds a few inches annually. The population of the EHR is approximately 584,000, which represents approximately 38 percent of the overall population of the LTEN River Basin. Most of the population is concentrated along the Tennessee River in northern Alabama. Huntsville, Ala., is the largest city, having a population of 160,000. The EHR was identified as one of the fastest growing areas in the lower Tennessee Valley between 1980 and 1995 (Kingsbury and others, 1999).

Physiography and Land Use

Mississippian-age carbonate rocks dominate the surficial geology of the EHR (Miller, 1974). These rocks are predominantly limestone with varying amounts of interbedded chert, clay, and shale. The most weather resistant of the Mississippian-age formations are the Fort Payne Formation and the St. Louis and Warsaw Limestones (based on State of Tennessee geologic nomenclature; refer to figure 2 for Alabama equivalent). Upper Mississippian-age formations are present along the southwestern boundaries of the EHR, the most prominent of which is the Hartselle Formation. The Hartselle Formation is easily recognized by its characteristic sandstone hills, known as Little Mountain (fig. 1), which are remnants where the surrounding area has been eroded to lower Mississippian-age formations.

Mississippian-age formations are underlain by the Devonian and Early Mississippian-age Chattanooga Shale, a thin layer of shale that restricts vertical movement of ground water between the Mississippian-age and the underlying Ordovician-age rocks. Ground water is deflected laterally, which results in numerous spring resurgences throughout the area. Water in these springs is generally sulfury as a result of elevated concentrations of iron sulfide and other minerals (Brahana and Bradley, 1986).

Soils across the EHR are varied. In the smooth upland areas of the EHR, soils have developed from weathered limestone, old alluvium, and silt deposits. Common soils include the Bodine-Mountview-Dickson series, and the Fullerton (Baxter) and Colbert types. These soils typically are well drained and moderately fertile (Springer and Elder, 1980). Along the eastern escarpment, soils are well drained and moderately fertile; however, cultivation is limited by the steep terrain and large amounts of cherty material in the soil. The most fertile soils are along the flood plains and terraces of the Tennessee River. These old terraces mostly are covered by several feet of loess and old alluvial material resulting in fertile soil well suited for cultivation.

Land use in the EHR is dominated by pasture (41 percent) and forest (27 percent), followed by cropland (16 percent), other (10 percent), urban (3 percent), and open water (3 percent) areas (Kingsbury and others, 1999) (fig. 3). Although cropland represents only 16 percent of the land use, the EHR still ranks highest among the ecoregions of the LTEN River Basin in cropland acres per square mile. The primary

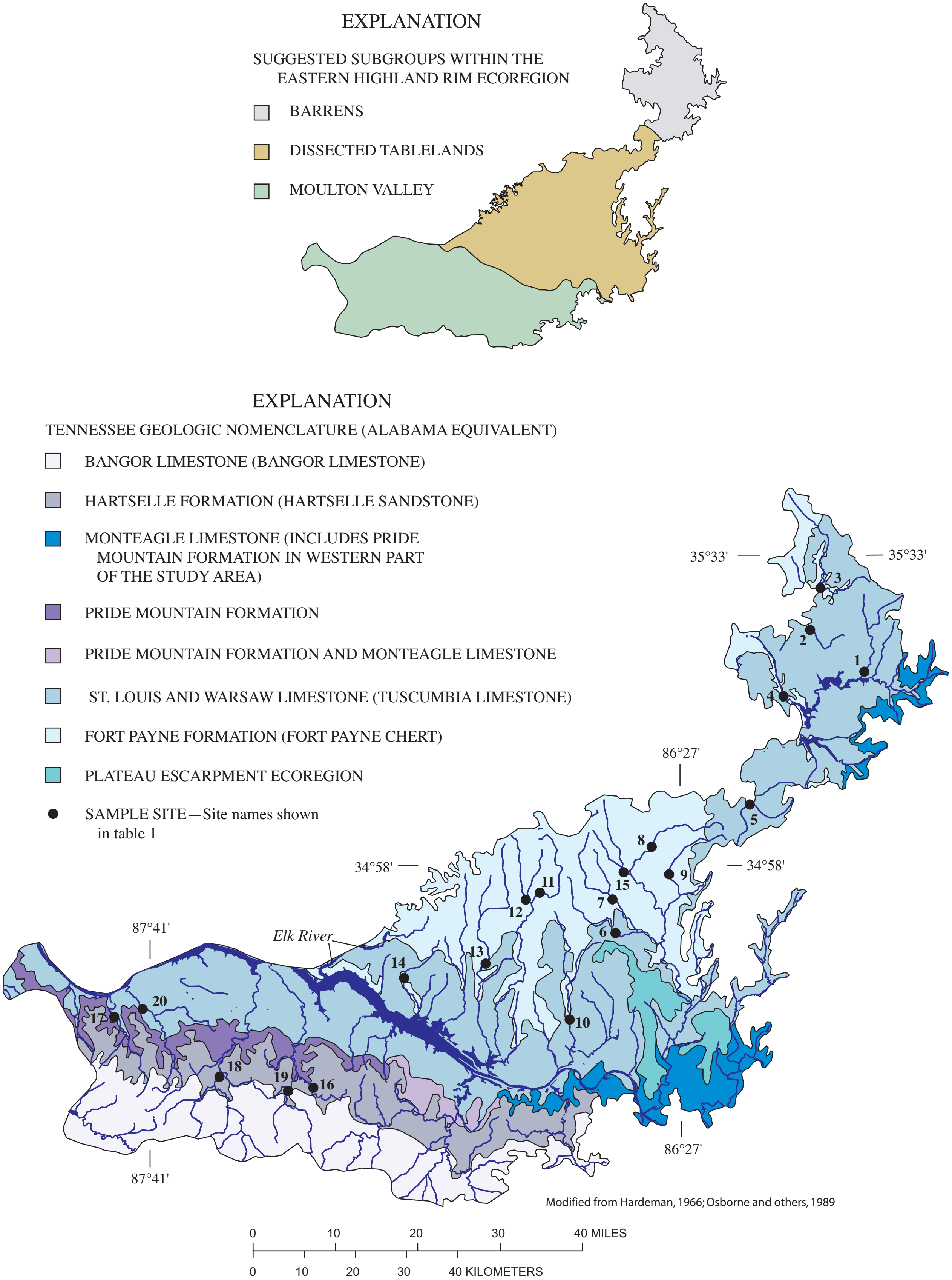
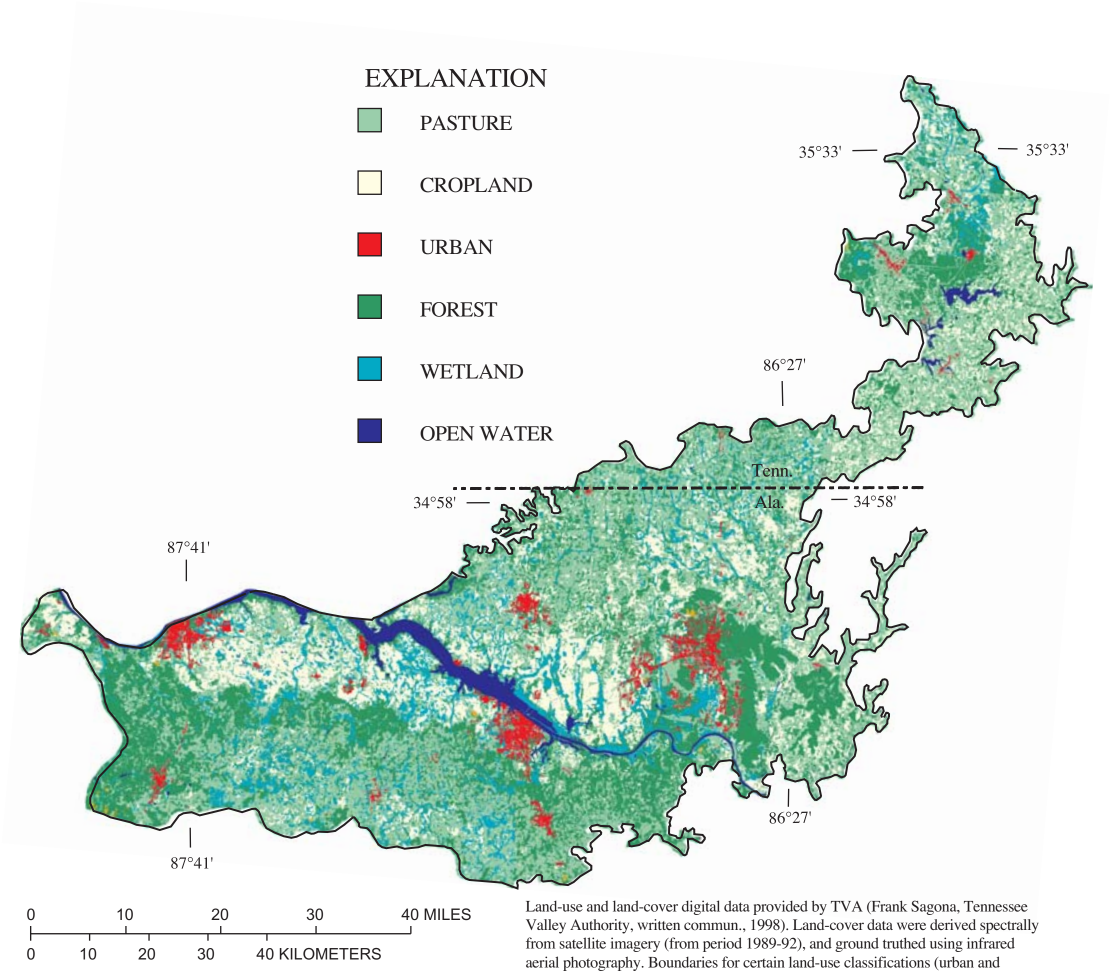


Figure 2. Location of sampling sites, generalized geology, and suggested subgroups in the Eastern Highland Rim Ecoregion of the lower Tennessee River Basin.



Land-use and land-cover digital data provided by TVA (Frank Sagona, Tennessee Valley Authority, written commun., 1998). Land-cover data were derived spectrally from satellite imagery (from period 1989-92), and ground truthed using infrared aerial photography. Boundaries for certain land-use classifications (urban and wetland areas) were digitized from topographic maps

Figure 3. Land use in the Eastern Highland Rim Ecoregion of the lower Tennessee River Basin.

row crops are cotton, corn, soybeans, and wheat. Pastureland is used for animal grazing, hay production, commercial nurseries, and confined animal feeding operations.

The Barrens (fig. 2) is a geologically unique area located along the northeastern boundary of the EHR. The name was first applied by the early settlers for its prairie-like landscapes. This area is characterized by flat karst topography and soils that are highly leached, acidic, and low in fertility. Vegetation is present that represents the northern Appalachians, the south Atlantic and Gulf Coastal Plains, and the northern prairies (Springer and Elder, 1980). The area is underlain by limestones, shales, and cherts of the Warsaw Limestone and Fort Payne Formation (Wolfe and others, 1997). Weakly dissected uplands with low relief, intermittent streams, and perennially wet, shallow pans also are characteristic of this area. The Barrens, which were once covered by warm season grasses, such as switch grass, Indian grass, and little bluestem, are now dominated by dense oak thickets.

Another unique area is the Moulton Valley, which is located along the southern margin of the EHR (fig. 2). The Moulton Valley is located between the western slope of the Cumberland Plateau Ecoregion and its intersection with the Coastal Plain Physiographic Province (figs. 1 and 2). This area is characterized by broad flat uplands, sandstone-capped ridges, and gently sloping broad valleys derived from old alluvial deposits. The isolated sandstone hills (Little Mountain) and steep slopes are remnants of the adjacent Cumberland Plateau. The weakly developed drainage pattern in the Moulton Valley includes a few permanent streams, however, most are intermittent. Most of the Moulton Valley is covered by forest in an area that was once heavily influenced by cultivation and livestock grazing.

The remaining area of the EHR consists of the Dissected Tablelands, which cover most of the EHR from the southern boundary of the Barrens to the Tennessee River (fig. 2). The terrain is flat with scattered limestone knobs and hills along its eastern boundary.

The Dissected Tablelands are underlain by the St. Louis and Warsaw Limestones. These limestones produce extensive cave and sinkhole systems throughout the area (Theis, 1936). The Dissected Tablelands include some of the most fertile soils in the EHR. The deep, red, loamy soils found along the lower Elk and Tennessee Rivers are farmed extensively. Most streams are perennial and flow southward in broad, shallow depressions, with low relief.

Fauna and Flora

Along with diverse landscapes and karst features, the EHR also is known for its unique fauna and flora (Etnier and Starnes, 1993; DeSelm, 1994). Having more than 100 native fish species, the EHR ranks as one of the most biologically diverse regions in North America (Etnier and Starnes, 1993; Mettee and others, 1996). The U.S. Fish and Wildlife Service currently (2002) lists two fish species in the EHR as being threatened or endangered—the slackwater darter (*Etheostoma boschungi*, threatened) and the Alabama cavefish (*Speoplatyrhinus poulsoni,* endangered). An additional seven species are considered rare throughout their range and likely will be considered candidate species in the future—ashy darter (*Etheostoma cinereum*), barrens topminnow (*Fundulus julisia*), Tuscumbia darter (*Etheostoma tuscumbia*), blotched chub (*Erimystax insignis*), flame chub (*Hemitremia flammea),* spring pygmy sunfish (*Ellasoma alabamae*), and southern cavefish (*Typhlichthys subterraneus)* (Etnier and Starnes, 1993; U.S. Fish and Wildlife Service, 2001). Two species are presumed extinct—the harelip sucker (*Lagochila lacera*) and the whiteline topminnow (*Fundulus albolineatus*) (Miller and others, 1989). The diversity of terrestrial plants is equally impressive; more than 1,000 species and varieties are present in the Barrens subregion alone (DeSelm, 1994), which composes over 39 percent of Tennessee's total vascular flora (Wofford and Kral, 1997). All common and scientific names follow nomenclature in Robins and others (1991).

The first recorded ichthyological surveys were conducted in the Tennessee River in the mid-1800s. Dr. D.H. Stoner reported at an 1845 meeting of the Boston Society of Natural History on nine species he had collected from the Tennessee River near Florence, Ala. (Agassiz, 1854). A few years later, Dr. Louis Agassiz reported on approximately 30 species from the same area (Agassiz, 1854). Until the mid-1800s, little was known about the diversity of fishes present in the Tennessee River and its tributaries. It also is interesting to note that Agassiz was already postulating ideas on how elevation and climate might influence fish distributions in the Tennessee River. In his closing remarks Dr. Agassiz stated, "The day is not far distant when we shall know with sufficient precision *where* all the living beings now existing upon the earth have made their first appearance." Today (2002) ichthyologists have documented between 205 and 215 native fishes from the Tennessee River system (Etnier and Starnes, 1993).

Flame Chub (*Hemitrema flammea*), State Rank—In need of Management. The flame chub typically is associated with springs; however, it is not restricted to springs. The greatest threats to the flame chub are alteration of spring habitats, increased sediment loads, and denuding of streambanks (Armstrong and Williams, 1971). (Photograph by M.D. Woodside, U.S. Geological Survey.)

Barrens topminnow (*Fundulus julisia*), State Rank—Threatened. The barrens topminnow is a Highland Rim endemic. This small topminnow prefers spring-like habitats that are heavily vegetated with plants such as watercress and filamentous algae (Etnier and Starnes, 1993). Once widely distributed in the upper Duck and Elk Rivers, recent surveys indicate that only isolated populations currently exist and may be extirpated from the Duck River altogether. Potential threats include alteration of springs and sedimentation. (Photograph by J.R. Shute, Conservation Fisheries, Inc. Used with permission.)

Since the turn of the 20th Century, many researchers and institutions have contributed to the identification and biogeography of fishes in the Tennessee River and the EHR. However, not until the 1980s were fish communities used as biological indicators of water quality in Tennessee Valley streams (Saylor and others, 1988; Saylor and Ahlstedt, 1996). The Tennessee Valley Authority (TVA) was one of the first Federal agencies in the Southeast to take a proactive approach in performing biological assessments at a watershed scale. These TVA studies were based on methods initially developed for streams in the Midwest by Karr (1981), where the primary objective was to assess the health of the stream using an Index of Biological Integrity (IBI). The IBI provides a numeric representation that can be used by managers and policy makers in making environmental decisions.

Historical Land Use

Naturally occurring (lightning) and human-induced fires have significantly altered the landscape in parts of the EHR for hundreds of years (DeSelm, 1994). Native Americans recognized the benefits of using fire to clear lands for grazing and also to stimulate plant growth. Many of the fires induced by Native Americans were believed to have occurred in the fall, during the driest season, hence the term “Indian Summer” (McClain, 2000). The first European settlers also recognized the usefulness of fire, but for different reasons. Milo Pyne (Nature Conservancy, written commun., 2000) suggests that the European settlers started fires in the spring, in hopes of combating and discouraging the Native Americans from burning their farmland. Fewer fires were started as more settlers moved into the area, thus again resulting in further landscape changes.

Agriculture has been and continues to be a major influence in the EHR. Along the fertile bottoms and terraces of the larger rivers, corn and cotton continue to be the staple row crops. Although lands along the river bottoms were intensively cultivated in the 1800s, pasture was by far the most dominant land use in the EHR (Killebrew and Safford, 1874). Along the rocky hillsides, which typically have shallow soils, hay production and cattle grazing dominated the landscape. According to one farmer, “Our soils are better adapted to the raising of grasses than any other crop, while it necessary in the States north of us to manure their meadows in order to ensure a good hay crop, I have never known one to be manured in this county, except from the droppings of stock. The grass grows profusely without any top dressing.” By the early 1900s, scientists had already witnessed the effects of careless agricultural practices. Programs that highlighted soil-loss prevention and control of water pollution were soon implemented to educate the farming community; however, the attitude of most farmers of this era was that it was cheaper to clear new fields than to pay close attention to fertilizing and cultivating previously cleared fields. Farmers were warned about the economic losses they would incur from extensive soil erosion resulting from shallow plowing.

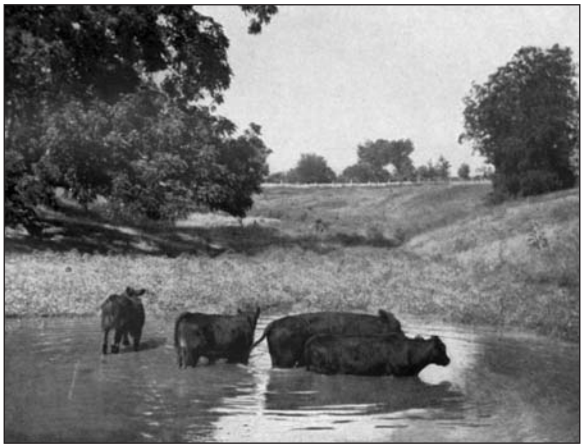
By the mid-1930s, the introduction of "super-phosphate" fertilizers were highly touted at a crop-enhancement technique that boosted crop yields and minimized soil erosion. (Photos from Tennessee Valley Authority Historic Collection. Used with permission.)

Protecting drinking-water supplies against agricultural-induced contamination became an important issue in the early 1900s. Occasional outbreaks of cholera, typhoid fever, and other enteric illnesses helped to maintain awareness of water quality (Switzer, 1914). Fuller (1910) emphasized the farmer’s need to protect streams, wells, sinkholes, and springs from potential contamination. Although maintaining aquatic

Safford (1869) describes landscape changes in the Barrens: *"It was a custom with the early settlers to burn off these lands every spring, in order that the barren grass, a strong, coarse, but nutritious herbage, might spring up and supply summer grazing for the cattle....There were but few trees, and those of an inferior kind of timber, being scrubby black jack, which, owing to the thickness of the bark, is able to resist the prairie fires. There was no undergrowth, and the strawberry vines laden with fruit in the spring filled the air with delightful odor. The wild honeysuckle, lady slipper, and wild pink contributed their fragrance and their flowers to the landscape. The soil, however, was poor. A cold, clammy, whitish soil, with here and there a marshy spot covered with large water oaks, which were protected from the fire by the character of their place of growth, was characteristic of the land in winter. A few settlers built houses along the margins of the wet weather streams and cleared a few acres. In order to protect their fences, fires were interdicted. A rank undergrowth of gum, hazel, hickory, and red oak sprung up. Red oaks, post oaks, and hickories shot up into the upper air. Several generations of leaves fell to the earth and rotted. The soil blackened....A good drainage supervened. Marshy places dried up, and the land became productive....Thirty years ago a cow or horse could be seen for miles, there being no undergrowth or timber to obstruct the view. It is impossible now to ride on horseback through the woods. Impenetrable thickets have sprung up, and all the features which distinguished the landscape thirty years ago, nearly all the characteristics of the country at that time, have disappeared."*

biodiversity was not the major concern for water quality in the early 1900s, the protection of biodiversity was an unintended outcome of the resource management practices promoted by scientists of this period.

The same soil and water issues present at the turn of the 20th Century in the EHR still exist today, although the amount of land under cultivation has continually decreased since the 1950s, and watersheds that were once cultivated and trampled by cattle are now covered by forest (U.S. Geological Survey, 2000). Harding and others (1998) report that some streams in the upper Tennessee River Basin, after years of flowing through farmlands, were ecologically impaired due to sedimentation from 50 years earlier. They concluded that the best predictor of present-day diversity of fishes could be land-use information from the 1950s. The ability to recognize and use past failures and successes will enhance the ability to monitor and protect aquatic resources in the future, while failing to consider past land-use patterns could result in biased and misleading results about how different present land-use practices affect water quality and biodiversity.



The farming community was already acknowledging water-quality concerns by the turn of the 20th Century. Concerns were primarily related to drinking-water supplies; however, other issues included preventing eutrophication of farm ponds and livestock water sources. (Photos from Fuller, 1910.)

Acknowledgments

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STUDY DESIGN

A gradient approach was used to evaluate the response of fish communities to changes in water chemistry and physical characteristics associated with varying degrees (gradient) of cropland. Interpretations from a gradient study of multiple watersheds can be transferred to the management problem of predicting how water chemistry will respond in a single watershed, considering changes in cropland percentages over time. By studying changes in water chemistry, habitat, hydrology, and fish communities, State and regional managers may predict with some degree of accuracy the effects of changing cropland allotments. This type of approach also can help managers decide on the appropriate cropland percentage at which they can most effectively meet, or achieve, designated water-quality standards.

While some degree of natural variability is expected within the EHR, ecoregion boundaries are delineated so that the natural variability within an ecoregion is relatively small (for example, compared with variability associated with human influence on the landscape). To further minimize natural variability, sites were selected from the same environmental setting by using the following criteria: (1) sites represented a range of 1 to 30 percent in cropland density; (2) sites had drainage basins ranging from about 30 to 100 square miles (mi^2); (3) the entire basin was within the EHR; (4) streams were third order or less; (5) urban areas were less than 4 percent in the contributing drainage area; and (6) streams were wadable. Selected sites were located far enough upstream of any major river or reservoir to minimize the influence of big-river or reservoir-type fishes (species that make seasonal spawning runs in the smaller streams). Based on these criteria, 20 streams were selected within the EHR and sampled during spring 1999 (table 1 and fig. 2).

SAMPLING METHODS

A variety of methods were used in this study, but all are based on a spatial hierarchy (basin, segment, and reach) as described by Fitzpatrick and others (1998). The reach, which is the principal unit at which physical, chemical, and biological field collections were made, was selected on the basis of a variety of instream channel features, such as distribution of geomorphic channel units (runs, riffles, and pools), wadability, width, and the absence of local disturbance or other discontinuous features within the identified stream. Generally, the length of the reach was determined by multiplying the average stream width by 20. The average reach length for streams sampled in the EHR was 656 feet. All field sampling activities were conducted between May and July 1999.

Environmental Characteristics

Physical characteristics consist of a combined set of habitat, hydrology, and land-use (HHL) variables. Habitat variables (table 2) were measured along 11 equidistant transects located within the sampling reach as described by Fitzpatrick and others (1998). Measurements of depth, velocity, dominant substrate, and percentage of substrate embeddedness were made at three instream points; bank angle, bank substrate, percentage of vegetative cover, and percentage of erosion were measured at each stream bank. Dominant substrate was determined by particle-size classes, and substrate embeddedness percentages were visually estimated in increments of 10. Bank angle, streambank vegetation, bank height, and bank substrate measurements were combined into a bank stability index prior to analysis (Fitzpatrick and Giddings, 1997). Riparian zones were characterized by canopy angle and canopy closure measurements. Canopy angles were measured by using a clinometer from the thalweg of the channel for left and right banks. An open canopy angle was then calculated by adding the two angles and dividing by 180 degrees. Canopy closure was measured at the water's edge with a concave spherical densiometer. The measurements from each transect were then summed and reported as a canopy cover percentage for the reach.

Hydrologic data collection consisted of an instantaneous streamflow measurement and an estimate of low flow. An instantaneous discharge measurement was collected once at each site in

Table 1. Basin characteristics of sampling sites for fish community, water chemistry, and physical habitat in the Eastern Highland Rim Ecoregion of the lower Tennessee River Basin

[NAVD 88, North American Vertical Datum of 1988; <, less than]

Site number (fig. 2)	Site name	Site abbreviation	Station identification number	Drainage area, in square miles	Elevation, in feet above NAVD 88	Land use, in percent			
						Pasture	Cropland density	Forest	Other
Barrens									
1	Bradley Creek near Prairie Plains, Tenn.	Bradley	03578502	45.1	970	50	20	30	<1
2	Crumpton Creek at Rutledge Falls, Tenn.	Crumpton	03596100	27.3	880	35	10	53	2
3	Little Duck River at Grindstone Hollow at Manchester, Tenn.	LitDuck	03595700	41.2	970	38	14	45	3
4	Rock Creek near Tullahoma, Tenn.	Rock	03579680	36.2	920	51	5	40	4
Dissected Tablelands									
5	Beans Creek at Brown Mill, Tenn.	Beans	03580787	48.5	820	45	19	36	<1
6	Beaverdam Creek near Meridianville, Ala.	Bdam	03574870	37.2	705	39	30	31	<1
7	Brier Fork near Hazel Green, Ala.	BrierF	03574823	40.8	740	56	14	29	1
8	Flint River at Lincoln, Tenn.	FlintLin	03574702	52.1	780	59	11	29	1
9	Hester Creek at Buddy Williamson Road near Plevna, Ala.	Hester	0357479650	29.3	760	50	15	35	<1
10	Indian Creek near Madison, Ala.	Indian	03575830	48.6	610	36	25	36	3
11	Limestone Creek near Toney, Ala.	Lime	03576207	27.8	770	55	12	33	<1
12	Little Limestone Creek near Toney, Ala.	LitLim	03576226	33.8	740	66	10	23	1
13	Piney Creek near Athens, Ala.	Piney	03576405	60.7	650	61	7	31	1
14	Round Island Creek near Lawson, Ala.	RndIs	03577490	34.0	585	52	17	28	3
15	West Fork Flint River near Hazel Green, Ala.	Wfork	03574750	39.6	750	56	14	28	2
Moulton Valley									
16	Clear Fork below Masterson, Ala.	ClearFk	03586400	27.3	570	52	1	45	2
17	Little Bear Creek near Tuscumbia, Ala.	LitBear	03590550	50.9	430	29	1	69	1
18	Mud Creek near Old Bethel, Ala.	Mud	03587378	48.4	560	46	5	47	2
19	Muddy Fork near Moulton, Ala.	Muddy	03586240	71.3	560	55	5	37	3
20	Spring Creek near Tuscumbia, Ala.	Spring	03590450	97.7	420	31	24	43	2

Table 2. Habitat, hydrology, and land-use variables used to characterize sites in the Eastern Highland Rim Ecoregion of the lower Tennessee River Basin

[m, meter; ft, foot; NAVD 88, North American Vertical Datum of 1988; mi^2, square mile; 7Q10, 7-day 10-year average discharge; ft^3/s, cubic foot per second]

Type	Habitat, hydrology, and land-use variable (units)	Abbreviation
Habitat	Segment sinuosity (ratio)	*sinuosity*
	Reach gradient (no unit)	*gradient*
	Reach as run habitat (percent)	*run*
	Reach as riffle habitat (percent)	*riffle*
	Reach as pool habitat (percent)	*pool*
	Average wetted channel width (m)	*WCwidth*
	Average bankfull width (m)	*BFwidth*
	Substrate as cobble (percent)	*cobble*
	Substrate as sand (percent)	*sand*
	Substrate as gravel (percent)	*gravel*
	Substrate as bedrock (percent)	*BR*
	Bank Stability Index (dimensionless)	*BSI*
	Open canopy (percent)	*opencanopy*
	Average depth (ft)	*depth*
	Substrate embeddedness (percent)	*embedded*
	Elevation at reach (ft above NAVD 88)	*elevation*
	Contributing drainage area (mi^2)	*DA*
Hydrology	Low-flow characteristic, 7Q10 (ft^3/s)	*LowBaseQ*
	Instantaneous streamflow (ft^3/s)	*Q*
Land use	Contributing basin in pastureland, 1992 (percent)	*pasture*
	Contributing basin in cultivated land, 1992 (percent)	*cropland*
	Contributing basin forested, 1992 (percent)	*forest*
	Contributing basin as forested wetlands, 1992 (percent)	*forwetland*
	Number of beef cows sold per year, 1997	*beefcow*
	Cows per acre of pasture, 1997 (head per acre)	*cowacre*

conjunction with the water sample. Depth and velocity were measured using a wading rod and pygmy meter according to procedures outlined in Buchanan and Somers (1969). Low-flow characteristics were estimated and used as a means of accounting for groundwater availability to streams during dry weather. The low-flow characteristics were estimated by using regression equations with the explanatory variables drainage area, annual precipitation, and mapped streamflow recession index. The low-flow characteristic used in this analysis was the lowest 7-day average discharge with a recurrence interval of 10 years as described by Bingham (1986) and Atkins and Pearman (1995).

Land-use and land-cover digital data were provided by the TVA (Frank Sagona, Tennessee Valley Authority, written commun., 1998). Boundaries for land-use classifications and individual drainage areas were delineated from 1:24,000 USGS topographic maps. Estimates of beef cattle density were obtained from the Watershed Characterization System (1999) (U.S. Environmental Protection Agency, 2000); calculations were based on watershed boundary and county-wide animal census data.

Water samples for chemical analysis were collected once at each site during normal springtime flows, when streamflow was stable, safely wadable, and was not affected by runoff from recent rainfall. Samples were collected by using depth- and width-integrating procedures as described by Shelton (1994) and analyzed for pH, dissolved oxygen, specific conductivity, fecal-indicator bacteria (*Escherichia coli*) and water temperature in the field. Nutrients (various forms of nitrogen and phosphorus), dissolved- and total-organic carbon, and major inorganic constituents (table 3) were analyzed at the USGS National Water Quality Laboratory (NWQL) in Lakewood, Colo.

Fish Communities

Fish were collected from each stream once between May and June 1999 by using procedures described by Meador and others (1993). Reaches were sampled by using a towed barge or backpack electroshocker and seine (6- by 15-foot by $^3/_{16}$-inch mesh). Each reach was fished once using a zigzag pattern. Following collection, all specimens were immediately identified, counted, observed for external lesions or deformities, and released downstream of the sample reach. Game fish (Centrarchids) were measured and weighed prior to releasing. All specimens were identified by the author and either by Amy B. Wales or Charles F. Saylor (aquatic biologists, TVA). Voucher specimens from each site, excluding threatened and endangered species, were preserved in a

Table 3. Water-chemistry variables used to characterize sites in the Eastern Highland Rim Ecoregion of the lower Tennessee River Basin

[^{o}C, degrees Celsius; µS/cm at 25 ^{o}C, microseimens per centimeter at 25 degrees Celsius; mg/L, milligrams per liter; µg/L, micrograms per liter; NTU, nephelometric turbidity units; col./100 mL, number of *Escherichia coli* colonies per 100 milliliters of sample water; N, nitrogen; P, phosphorus]

Water-chemistry variable (units)	Abbreviation
Water temperature (^{o}C)	*temp*
pH	*pH*
Specific conductivity (µS/cm at 25 ^{o}C)	*spcond*
Alkalinity (mg/L)	*alk*
Ammonia, dissolved (mg/L as N)	*NH4*
Nitrite, dissolved (mg/L as N)	*NO2*
Ammonia plus organic nitrogen, dissolved (mg/L as N)	*NH4dis*
Ammonia plus organic total nitrogen (mg/L as N)	*NH4total*
Nitrite plus nitrate, dissolved (mg/L as N)	*NO2NO3*
Total phosphorus (mg/L as P)	*P*
Phosphorus, dissolved (mg/L as P)	*Pdis*
Ortho-phosphorus, dissolved (mg/L as P)	*Portho*
Total organic carbon (mg/L)	*TOC*
Dissolved organic carbon (mg/L)	*DOC*
Total nitrogen (mg/L)	*N*
Turbidity (NTU)	*turbid*
Escherichia coli (col./100 mL)	*EC*
Calcium, dissolved (mg/L)	*CA*
Silica, dissolved (mg/L)	*SIO2*
Iron, dissolved (µg/L)	*FE*
Potassium, dissolved (mg/L)	*K*
Sodium, dissolved (mg/L)	*NA*
Chloride, dissolved (mg/L)	*CL*
Magnesium, dissolved (mg/L)	*MG*
Fluoride, dissolved (mg/L)	*F*
Manganese, dissolved (mg/L)	*MN*
Sulfate, dissolved (mg/L)	*SO4*

A variety of sampling methods and techniques were used to collect fish. Seining is an effective technique for sampling in debris-free pools and backwater eddies. Seining also limits the stress induced by electrofishing. Riffles and fast flowing sections were sampled by electrofishing into a seine that was placed perpendicular to the flow and downstream of the electrofishing unit. (Photographs by R.R. Knight, U.S. Geological Survey.)

10-percent formalin solution and archived in the University of Tennessee Research Collection of Fishes (University of Tennessee, Knoxville) and in the University of Alabama Ichthyological Collection.

ANALYTICAL METHODS

Responses of fish communities to cropland density and natural environmental setting were determined by (1) identifying the chemical and physical characteristics that explain most of the variability among sites, (2) determining whether those characteristics were associated with cropland density or were caused by natural environmental variability, and (3) identifying which environmental characteristics influenced fish-community structure. Three data sets were used to describe 20 sites in the EHR—fish-community (response variable), water-chemistry (chemical environmental variables), and combined data set of HHL characteristics (physical environmental variables). Two ordination procedures, principal components analysis (PCA) and correspondence analysis (CA), were used to describe patterns in the data. PCA was used for exploratory data analysis to identify the most important environmental variables related to natural setting and cropland density; CA and PCA were used to summarize fish communities (abundance and metrics, respectively); and an indirect gradient analysis was used to determine the response of fish communities (CA and PCA) to cropland density and natural environmental variability. In addition, an IBI was used to determine and compare fish-community response to cropland density, natural environmental variability, and results from the CA and PCA.

Environmental Characteristics

Environmental data were analyzed separately using ordination of PCA, which was initially used for exploratory data analysis to identify the most important variables within each data set. PCA identifies axes (gradients) that are linear combinations of the original variables. The first PCA axis explains most of the variance, and each successive axis accounts for a decreasing amount of the remaining variance. Individual variables along an axis are expressed as variable loadings to indicate relative importance. These variable loadings can be used to identify the most important variables associated with each axis. An arrow represents each environmental variable where the arrow's length is an indication of the relative importance of the variable to the axis; for example, long arrows are more important than short arrows.

PCA also was used for indirect gradient analysis to relate the most important gradients, usually the first two or three axes, to cropland density and natural environmental setting. Site scores (also called eigenvectors) for selected axes were correlated with cropland density to determine whether the PCA gradients were associated with natural environmental characteristics or cropland density. Site scores are coordinates along an axis specifying the location of sites along the environmental gradient. Sites having similar characteristics, or scores, cluster together, and sites having dissimilar characteristics are located farther apart. Prior to running the PCA, all data were standardized to a mean of 0 and standard deviation of 1. PCA was performed using the computer program Multivariate Statistical Package (Kovach, 1998).

Fish Communities

Fish communities were summarized and analyzed separately by using (1) CA, which is based on species abundance; (2) PCA, which is based on individual community metrics; and (3) IBI, which is based on a combined set of community metrics. CA and PCA are considered ordination procedures; however, PCA assumes a linear response, whereas CA assumes a unimodal, or bell-shaped, response. The unimodal response model is important because fish abundance rarely responds linearly to environmental changes. Every fish species, for example, adapts to its own optimal range of environmental conditions, such as pH, dissolved oxygen, or temperature, and conditions outside this range will result in a decrease in abundance of the species. Relative abundance values used in the CA were arcsin transformed (Zar, 1999), and rare species were downweighted prior to analysis. This transformation prevents extremely abundant or extremely rare values from having undue influence on the analysis (Gauch, 1982). Although non-native and big-river species were rarely collected, all data for these species were removed prior to analysis to minimize undue bias. CA was performed using the Multivariate Statistical Package (Kovach, 1998).

PCA was used to analyze 14 community metrics that are presumed indicators of anthropogenic disturbance (table 4). PCA was used rather than CA because metrics tend to respond to environmental changes

Table 4. Fish-community metrics used to summarize groups of fishes in the Eastern Highland Rim Ecoregion

[Refer to Appendix 4 for species classifications; LTEN, lower Tennessee; DELTs, deformities, lesions, and tumors]

Fish-community metric (abbreviation)	Description and rationale for use
Number of darter species (*darters*)	Darters are benthic dwelling fishes, therefore, they tend to be sensitive to many forms of anthropogenic perturbations, such as channelization, siltation, and reduced dissolved oxygen levels (Karr and others, 1986).
Percentage of individuals as specialized insectivores (*spinsect*)	Specialized insectivores compose the largest trophic class of fishes in the LTEN River Basin. A decrease in percentage typically is related to a decline in the insect community, which in turn may reflect degrading water-quality and instream habitat conditions (Karr and others, 1986).
Number of native species (*natives*)	The number of native species metric is based on the premise that the number of native species will decline with increased environmental disturbance (Karr and others, 1986). The exclusion from the metric of all non-native species provides a more accurate asssessment of overall biotic integrity.
Number of sunfish species (*sunfish*)	Sunfish species are sensitive to degradation of pool habitat (Ohio Environmental Protection Agency, 1987).
Percentage of individuals as simple lithophilic spawners (*simLiths*)	The term simple lithophils refers to the spawning behavior of fishes that broadcast their eggs across cobble- and gravel-sized substrates where eggs are left to develop in the interstitial spaces (Simon, 1999). Simple lithophils require clean gravel and cobble to successfully reproduce. The negative relation between percentage of simple lithophils and degree of siltation was documented by Berkman and Rabeni (1987).
Percentage of individuals as omnivores and stonerollers (*omnivores*)	This metric has been modified to include stonerollers (*Campostoma oligolepis*) and represents fishes commonly classified as "opportunist" and "generalist." The stoneroller is a grazing minnow that uses the cartilagenous ridge located below the jaw to scrape and feed on algae and detritus (Jenkins and Burkhead, 1993). Stonerollers feed in schools and have been known to significantly alter algal community composition and distributions (Power and Mathews, 1983).
Percentage of individuals with external anomalies (*anomalies*)	External anomalies include tumors, lesions, fin damage, skeletal deformities, or any other indication of external damage. Black spot was included in the metric. Studies indicate that the percentage of individuals with external anomalies increase at degraded sites, particularly downstream of municipal and industrial wastewater discharges (Ohio Environmental Protection Agency, 1987).
Catch rate (*catchrate*)	Catch rate is synonymous with the number of individuals in a given sample. Catch rate is expressed in this report as the number of individuals collected per 300 square feet. Catch rate generally decreases as water-quality and habitat conditions deteriorate; however, catch rate can actually increase in streams that are artifically enriched with nutrients (Barbour and others, 1999).
Number of sucker species (*suckers*)	Similar to sunfish, suckers are most sensitive to degradation of overall habitat conditions. Because of their longevity, suckers also are good indicators of past conditions (some sucker species can live up to 20 years) (Karr and others, 1986).
Number of intolerant species (*intols*)	Intolerant species are those for which abundances decrease due to anthropogenic impacts. Karr and others (1986) suggest that increase in siltation is the primary factor associated with a decrease in the number of intolerant species.
Percentage of individuals as tolerant species (*tolerant*)	Tolerant species typically become the dominant species in severely degraded streams (Ohio Environmental Protection Agency, 1987).
Percentage of individuals as hybrids (*hybrid*)	The hybrid metric is an estimate of the reproductive capacity of the habitat (Ohio Environmental Protection Agency, 1987). It is often substituted for the simple lithophils metric, reflecting the opposite conditions. For example, the percentage of hybrids increases as spawning conditions degrade.
Percentage of individuals as piscivores (*pisc*)	The piscivore metric is designed to reflect fish that feed, as adults, on other fish and crayfish (Ohio Environmental Protection Agency, 1987). Goldstein and Simon (1999) discuss the piscivore group in greater detail by using terms for types of feeding strategies, such as "stalkers," "chasers," "ambushers," and fish that have a "protective resemblance" to their environment.
Percentage of individuals with DELTs (*DELT*)	Similar to the percentage of individuals with external anomalies metric, the DELT metric includes all external anomalies minus black spot. Black spot and some other parasites may be present on individuals and not linked to factors associated with poor water quality.

linearly rather than unimodally. Community metrics are a convenient way of grouping fish taxa based on shared ecological or taxonomic characteristics. Metrics are used to simplify complex multivariate data in such a way that a change in one or more of the metric values is indicative of some level of perturbation. Each metric is designed to change in a predictable way that reflects some change in the environment (Barbour and others, 1999). Individual metrics were selected on the basis of their potential to respond to anthropogenic disturbance in a predictive way. Prior to running the PCA, observed values were standardized to a mean of 0 and standard deviation of 1 to facilitate comparisons involving multiple units of measurement.

The IBI, an integrated index based on 12 of the 14 metrics used in the PCA, also was calculated for each site. The 12 metrics used in the IBI calculation were selected because of their usage by other agencies. Criteria for IBI calculation were developed by the TVA and are used for similar size streams located within the Interior Low Plateau Physiographic Province. The IBI provides a more holistic approach to fish-community assessment, while the analysis of individual metrics allows comparisons of specific aspects of the community.

Response of Fish Communities to Cropland Density and Environmental Characteristics

Indirect gradient analysis was used to relate fish-community characteristics and environmental variables related to natural setting and the *a priori* cropland-density gradient. The IBI additionally was used as a procedure to determine whether a multimetric index is influenced by natural environmental setting and cropland density and to compare the sensitivity of an integrated index to the results of CA. Spearman-rank correlation analysis was performed on the combined data set creating a matrix of correlation coefficients (Spearman's rho). Correlations were evaluated by generating simple scatter plots and were individually tested for significance (judged significant when $p<0.05$) by using S-Plus statistical software (MathSoft, 1999).

ENVIRONMENTAL CHARACTERISTICS AND FISH COMMUNITIES IN THE EASTERN HIGHLAND RIM ECOREGION

Environmental and fish-community characteristics were summarized for 20 sites in the EHR in 1999. The following section presents results from the ordination of the environmental and fish-community data, identification of environmental characteristics associated with cropland density and natural setting, and response of fish communities to cropland densities and natural environmental setting.

Physical Characteristics

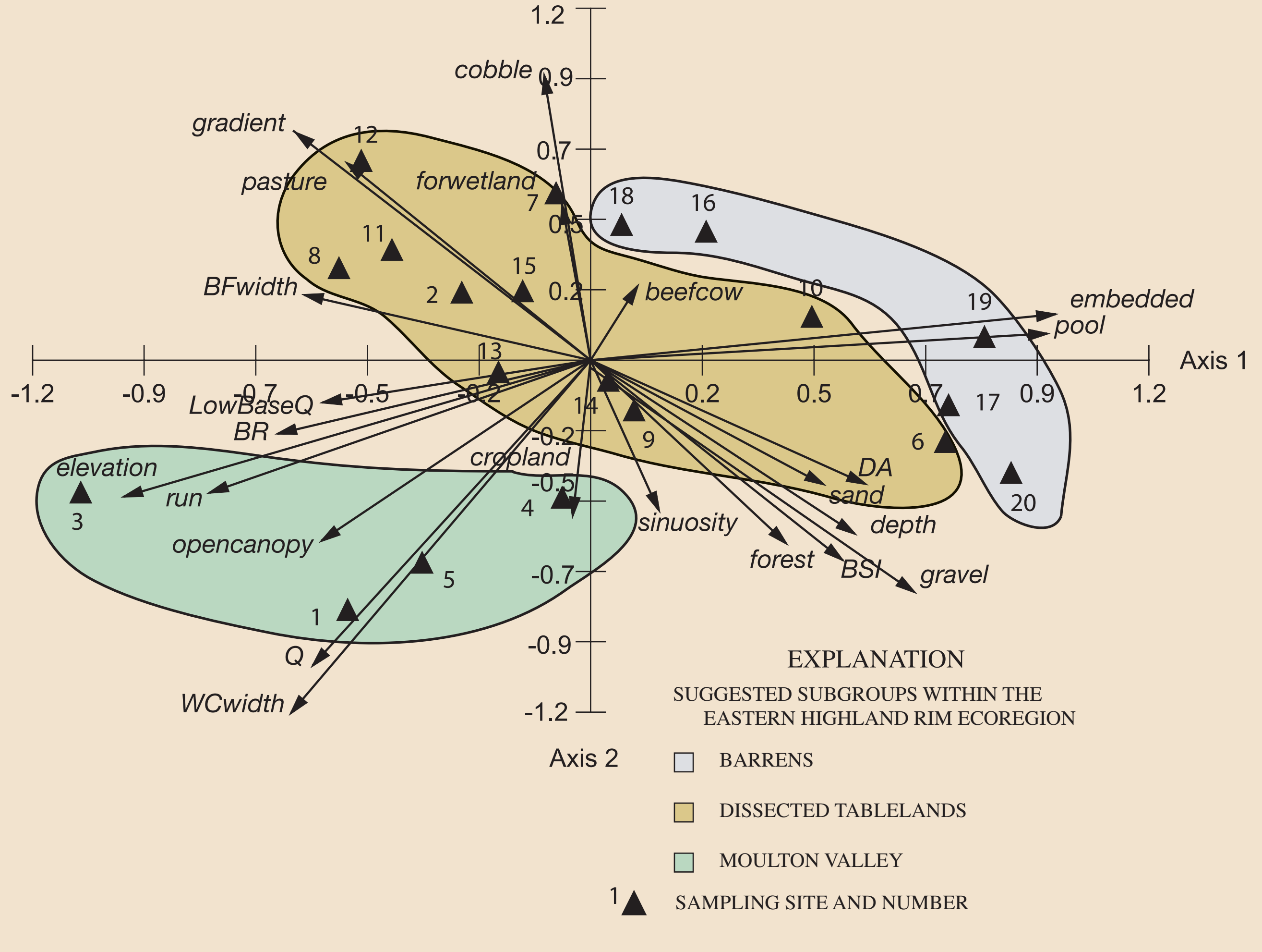
A total of 25 HHL variables were measured at sites in the EHR. Pasture (ranging from 29 to 66 percent, table 1) and forest (ranging from 23 to 69 percent) were the predominant land uses, mixed with a gradient of cropland densities (ranging from 1 to 30 percent). Elevations ranged from 420 feet above NAVD 88 at Spring Creek near the southern boundary to 970 feet above NAVD 88 at Bradley Creek and Little Duck River near the northern boundary of the EHR. The areas of the contributing basins, which can dramatically influence fish distributions, ranged from 27.3 to 97.7 mi^2. Instantaneous streamflow measurements (*Q*) ranged from 5.3 to 113 cubic feet per second (ft^3/s) at Clear Fork and Bradley Creek, respectively, and low-flow estimates (*LowBaseQ)* ranged from 0.04 to 13 ft^3/s.

Results from the ordination of the HHL data indicate that the dominant gradients are related to variability in natural setting more than to variability associated with anthropogenic disturbance. The most important variables along the first axis (based on variable loadings) were elevation (*elevation*), streamflow (*LowBaseQ*), and other intercorrelated variables, such as reach-gradient (*gradient*) and instream habitat characteristics (*pool*, *embedded*, *opencanopy*, *depth*, and *WCwidth*) (table 5; fig. 4). Sites 3, 1, 5, and 8 at the upper end of the elevation gradient also had wider channels (*BFwidth*), increased streamflow (*Q* and *LowBaseQ*), higher percentages of pasture (*pasture*), and increased reach-gradient (*gradient*) than sites 17, 20, 19, and 6 at the lower end of the gradient, which had increased pool habitat (*pool*), substrate embeddedness (*embedded*), and deeper channels (*depth*) (fig. 4). The primary variables along the second axis are related to instream conditions, such as wetted channel width (*WCwidth*), substrate size (*cobble* and *gravel*), and flow (*Q*). The third axis was related to streamflow (*Q* and *LowBaseQ*), channel depth (*depth*), and percentage of the basin in vegetated wetlands (*forwetland*), indicating that basins with increased streamflow (*Q* and *LowBaseQ*) also have less vegetated wetlands

Table 5. Summary statistics from the principal components analysis of the habitat, hydrology, and land-use variables for 20 sites in the Eastern Highland Rim Ecoregion

[Variable abbreviations are listed in table 2; bolded variable loadings were considered important when absolute values were 0.2 or greater; HHL, habitat, hydrology, and land use]

HHL variable	Variable loadings		
	Axis 1	Axis 2	Axis 3
beefcow	0.03	0.09	-0.19
DA	**0.20**	-0.14	-0.16
Q	**-0.21**	**-0.36**	**0.23**
LowBaseQ	**-0.20**	-0.05	**0.46**
cropland	-0.01	-0.18	0.19
pasture	-0.18	**0.23**	0.01
forest	0.14	**-0.21**	0.02
forwetland	-0.02	0.18	**-0.36**
elevation	**-0.35**	-0.16	**0.20**
sinuosity	0.05	-0.17	0.18
gradient	**-0.22**	**0.27**	**0.20**
run	**-0.28**	-0.16	**-0.25**
pool	**0.34**	0.03	0.11
WCwidth	**-0.22**	**-0.41**	-0.10
BFwidth	**-0.21**	0.08	-0.14
BSI	0.19	**-0.23**	-0.02
opencanopy	**-0.20**	**-0.21**	-0.06
depth	**0.20**	**-0.20**	**0.30**
embedded	**0.34**	0.05	**0.21**
BR	**-0.23**	-0.09	-0.15
cobble	-0.03	**0.33**	**0.33**
gravel	**0.24**	**-0.26**	-0.17
sand	0.17	-0.14	-0.05
cowacre	0.02	-0.15	**-0.28**
Eigenvalues	5.25	3.33	2.63
Percentage of variability in data set explained by axis.	22.84	14.49	11.43
Cumulative percentage of variability in data set explained by axis.	22.84	37.33	48.77



Note: Site numbers are identified in table 1. HHL abbreviations are identified in table 2. The location of the sites (based on site scores) along each ordination axis specifies the location of the site relative to the axis. Variables are represented by arrows and sites are represented by triangles. Each axis is a linear combination of multiple variables, where sites located near one another have similar characteristics and those located far apart have dissimilar characteristics. Subgroup colors correspond to Ecoregion map shown on figure 2.

Figure 4. Principal components analysis biplot illustrating the relation among habitat, hydrology, and land-use (HHL) variables for 20 sites in the Eastern Highland Rim Ecoregion.

(*forwetland*) and occur at higher elevations (*elevation*) than other basins.

Ordination using PCA also was used to indirectly relate indirect gradient analysis differences in natural environmental setting to differences in cropland density. PCA site scores, which are coordinates along an axis specifying the location of the site relative to the axis, were correlated against cropland density. The first two ordination axes indicate that none of the axes, or any of the individual HHL variables, were significantly correlated with cropland density. Substrate embeddedness, although an important variable along the first axis, is not significantly correlated with cropland density (rho=0.10). Instead, substrate embeddedness was related to sites at low elevations having high percentages of pools. Clustering of sites along the first and second axes indicates that sites vary regionally on the basis of differences in elevation and streamflow. For example, sites in the Moulton Valley were characterized by a different group of variables (increase in *pool*, *embedded*, *sand*, and *depth*) than were sites located in the Barrens and Dissected Tablelands subregions (increase in *elevation*, *Q*, *LowBaseQ*, *WCwidth*, and *opencanopy*), indicating that HHL variability is primarily caused by differences in natural setting.

Variation of Natural Environmental Setting within the Eastern Highland Rim Ecoregion

Results of the PCA of the HHL data indicate that differences in elevation and streamflow among sites in the EHR are the most important components of variability and may control variability in many instream habitats as well. This finding belies the fact that the EHR was delineated for the sole purpose of minimizing variability of natural setting. The ordination plots and distribution of elevation and streamflow values across the EHR were examined. The results suggest that the 20 EHR sites should be divided into three subgroups with similar natural settings, such as sites in the Moulton Valley, Barrens, and the Dissected Tablelands (fig. 5).

Differences in elevation and streamflow among these three subgroups were tested using a Kruskal-Wallis test (MathSoft, 1999). The Kruskal-Wallis test determines whether a difference exists among one or more groups, but does not identify which group is different. A difference was detected, and the Wilcoxon rank-sum test was performed on pairwise combinations of the subgroups to verify statistical differences among all three subgroups. For example, sites in the Moulton Valley are at lower elevations, have lower streamflows, have a higher percentage of pool habitat, and have more embedded substrates than sites located in either the Barrens or Dissected Tablelands subgroups. The Tennessee River was then selected as the northern Moulton Valley boundary. Segregation of the remaining sites into appropriate subgroups was not as straightforward. Surficial geology, along with elevation and streamflow, were the primary criteria used to divide the sites into either the Barrens or the Dissected Tablelands subgroup. The presence of the Fort Payne Formation and the St. Louis and Warsaw Limestones as dominant substrate features was used to separate sites in the Barrens from those in the Dissected Tablelands subgroup.

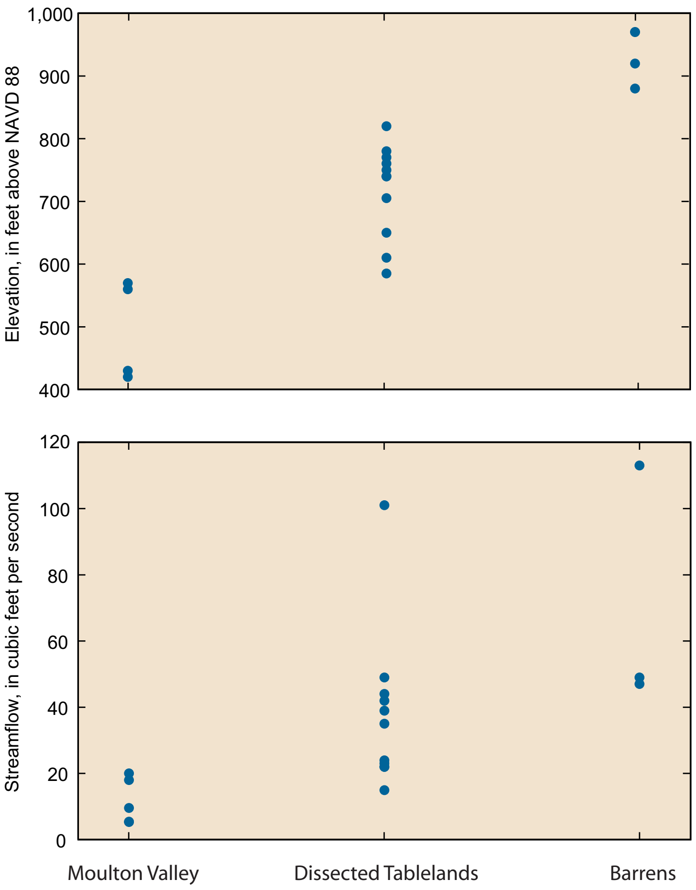


Figure 5. Differences in elevation and streamflow among 20 sites in the Eastern Highland Rim Ecoregion, summarized by natural setting or ecoregion subgroup.

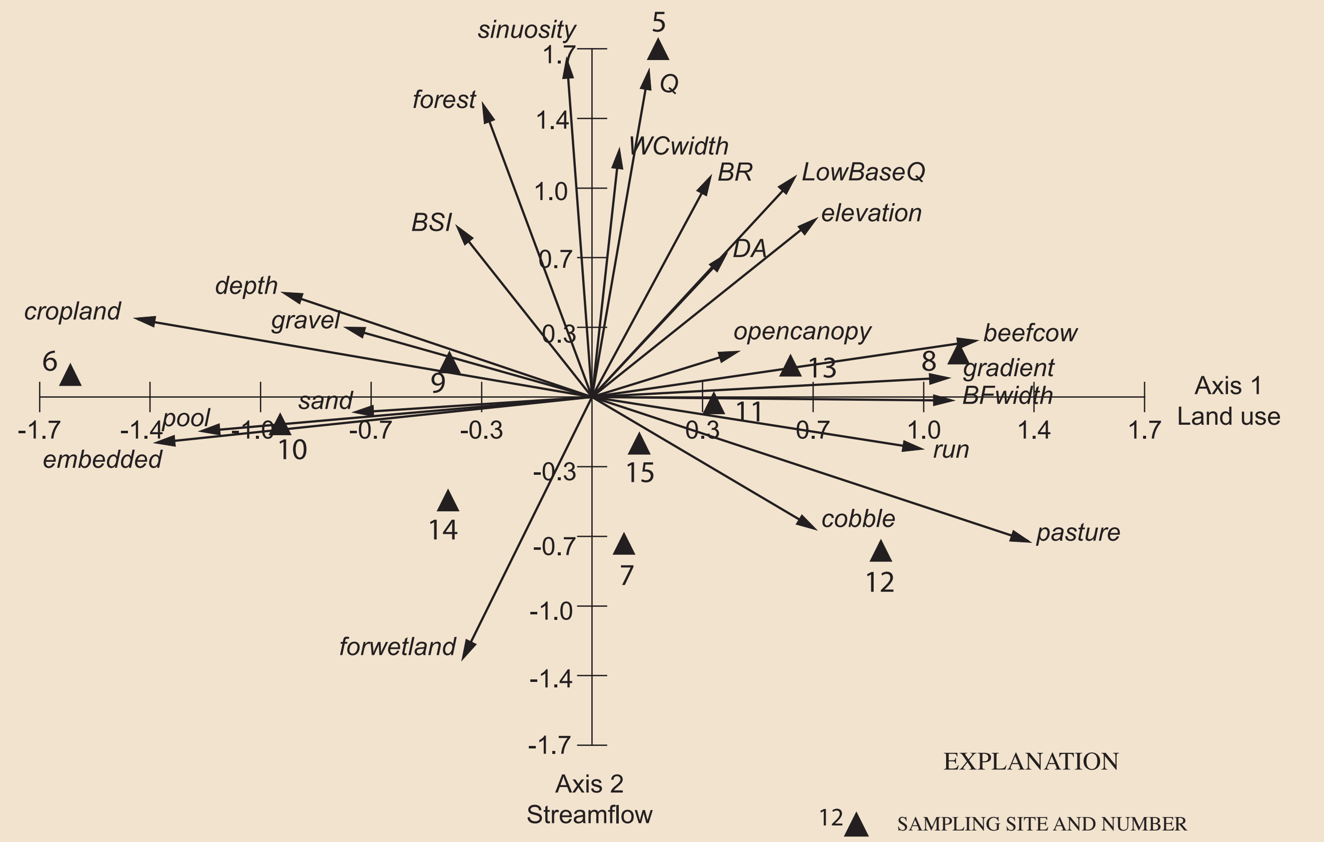
The HHL data were re-analyzed for sites located in the Dissected Tablelands. The Dissected Tablelands was selected because of the large number of sites, which added statistical power to the analysis. The percent of cropland in the Dissected Tablelands ranged from 7 to 30 percent (table 1), which is similar to the range of cropland percentages that was initially provided by the 20 sites in the EHR; however, data for sites at the low end of the gradient (less than 7-percent cropland) were not used. Elevations in the Dissected Tablelands ranged from 585 to 820 feet above NAVD 88, and streamflows ranged from 15 to 101 ft^3/s for *Q*, and from 0.55 to 13 ft^3/s for *LowBaseQ*.

Results from the PCA for sites in the Dissected Tablelands indicate that land use (*pasture* and *cropland*) and other intercorrelated variables (*beefcow*, *gradient*, *embedded*, and *BFwidth*) were the most important HHL variables along the first axis (table 6 and fig. 6). Sites 6, 9, and 10, which have high percentages of cropland also were associated with a high degree of substrate embeddedness, an increased abundance of pool habitat, deep channels, and a high percentage of fine substrates (*sand*). Pastureland was at the opposite end of the land-use gradient. Increases in pastureland were typically associated with increased numbers of beef cows, wide stream channels (*BFwidth*), and cobble-sized substrate. Along the second axis, the most important variables were related to natural

Table 6. Summary statistics from the principal components analysis of the habitat, hydrology, and land-use variables for 11 sites in the Dissected Tablelands

[Variable abbreviations are listed in table 2; bolded variable loadings were considered important when absolute values were 0.2 or greater; HHL, habitat, hydrology, and land use]

HHL variable	Variable loadings (see fig. 6)	
	Axis 1 Land use	Axis 2 Streamflow
beefcow	**0.30**	0.07
DA	0.10	0.17
Q	0.04	**0.39**
LowBaseQ	0.16	**0.27**
cropland	**-0.35**	0.10
pasture	**0.34**	-0.18
forest	-0.08	**0.35**
forwetland	-0.10	**-0.32**
elevation	0.17	**0.22**
sinuosity	-0.02	**0.41**
gradient	**0.27**	0.02
run	**0.25**	-0.06
pool	**-0.30**	-0.04
WCwidth	0.02	**0.30**
BFwidth	**0.28**	0.00
BSI	-0.10	**0.20**
opencanopy	0.11	0.05
depth	**-0.24**	0.13
embedded	**-0.33**	-0.06
BR	0.09	**0.27**
cobble	0.17	-0.16
gravel	-0.19	0.08
sand	-0.18	-0.02
cowacre	**0.28**	0.04
Eigenvalues	6.56	4.41
Percentage of variability in data set explained by axis.	28.54	19.19
Cumulative percentage of variability in data set explained by axis.	28.54	47.73



Note: Site numbers are identified in table 1. HHL abbreviations are identified in table 2. The location of the sites (based on site scores) along each ordination axis specifies the location of the site relative to the axis. Variables are represented by arrows and sites are represented by triangles. Each axis is a linear combination of multiple variables, where sites located near one another have similar characteristics and those located far apart have dissimilar characteristics. The length of the arrow indicates the relative importance of the variable to the axis. The location of the sites (based on site scores) along each ordination axis specifies the location of the site relative to the axis. Each axis is a linear combination of multiple variables.

Figure 6. Principal components analysis biplot illustrating the relation among habitat, hydrology, and land-use (HHL) variables for 11 sites in the Dissected Tablelands.

environmental setting and included streamflow (*Q* and *LowBaseQ*), percentage of basin in forest, and channel morphology (*sinuosity* and *WCwidth*).

The indirect gradient analysis indicates that the primary gradient (axis 1) was related to cropland density (land-use gradient) (fig. 7). The most important factors were related to land use (*pasture* and *cropland*) and other intercorrelated variables (*beefcow*, *gradient*, *embedded*, and *BFwidth*) (table 6). However, embeddedness, which is often associated with storm runoff from cultivated fields, was the only variable directly correlated with cropland density (fig. 7). The second axis (streamflow gradient) was best explained by differences associated with natural setting. Variables included streamflow (*Q* and *LowBaseQ*), percent forest, and channel morphological characteristics (*sinuosity* and *WCwidth*).

Analyzing sites in the Dissected Tablelands separately from those in the entire EHR reduced environmental variability because of natural factors. Although nine sites were removed from the analysis, the likelihood of detecting relations between fish communities and cropland density increased. To verify that fish communities also differed regionally, fish-community data for the entire EHR were analyzed by CA, PCA, and IBI summaries prior to the analyses on the Dissected Tablelands subgroup (appendixes 1 and 2). Results of the CA indicated the same regional patterns as suggested by the HHL analysis. The remainder of the report discusses data for the 11 sites in the Dissected Tablelands only.

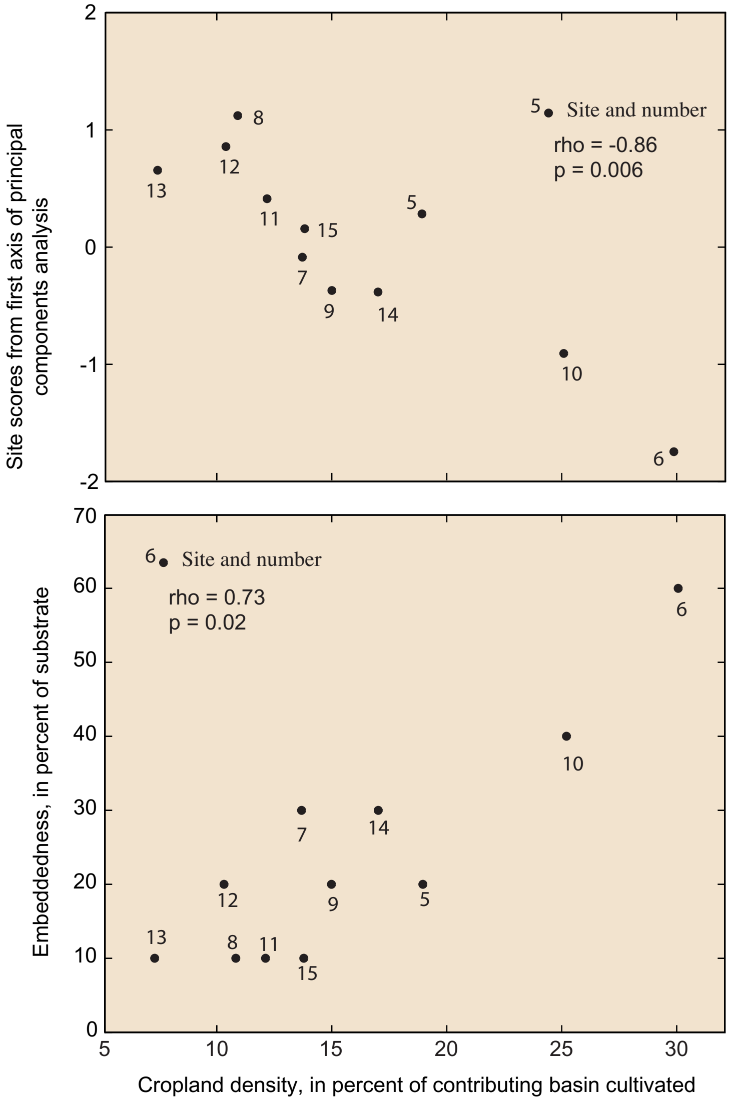


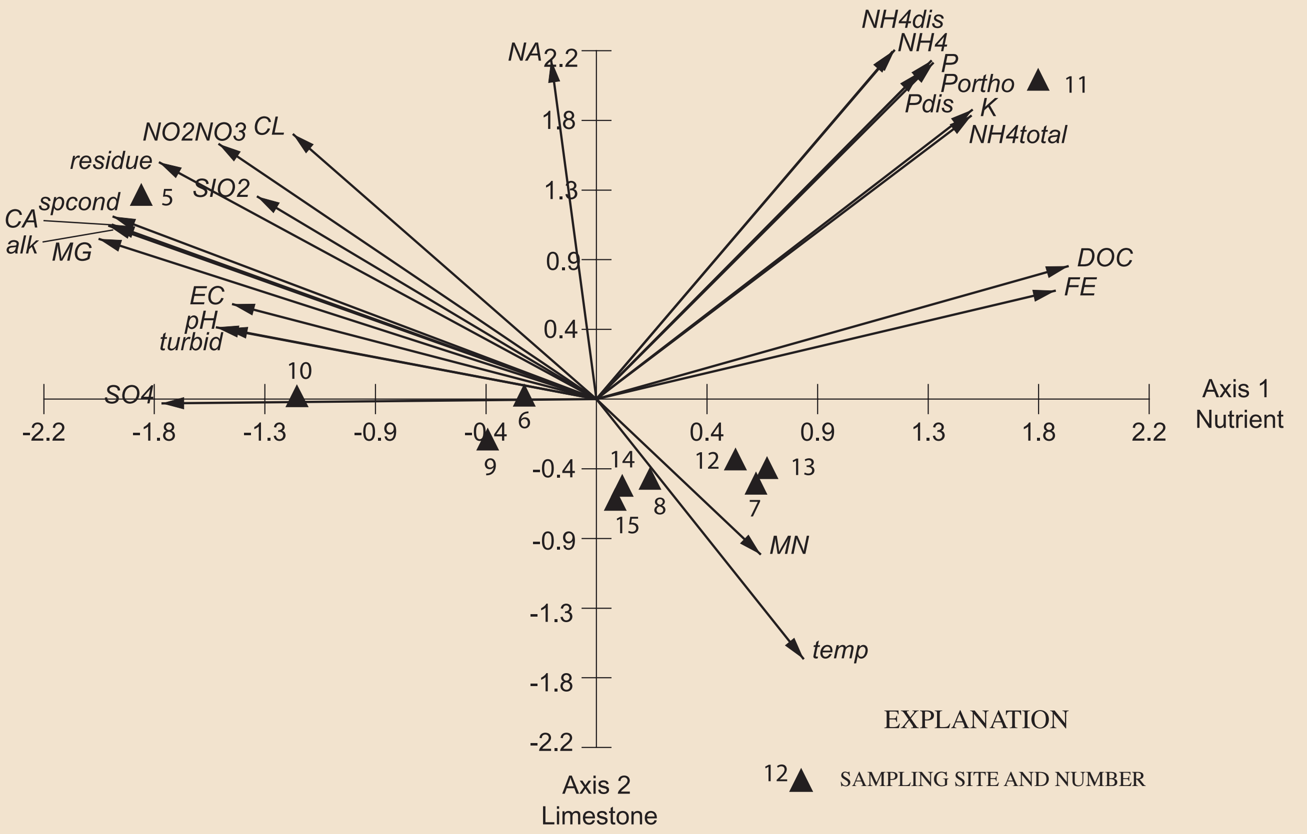
Figure 7. Comparison of cropland density to site scores from the first axis of the principal components analysis (habitat, hydrology, and land-use variables) and substrate embeddedness for 11 sites in the Dissected Tablelands. (Numbers represent site numbers shown in table 1.)

Water Chemistry

Differences in water chemistry of streams in the Dissected Tablelands primarily were related to specific conductivity, which was similar to that for the 20 sites in the entire EHR. Specific conductance (*spcond*), which is commonly used to indicate ground-water resurgence, ranged from 64 to 289 microsiemens per centimeter (µS/cm) at 25 degrees Celsius. Nitrogen and phosphorus levels, which can increase as a result of storm runoff from adjacent croplands, ranged from 0.79 to 3.7 milligrams per liter (mg/L) for nitrite plus nitrate (*NO2NO3*) as N and from 0.01 to 0.12 mg/L for orthophosphorus (*Portho*) as P. Other variables such as temperature (*temp*), turbidity (*turbid*), and inorganic constituents, which can also be influenced by landscape disturbance, displayed little variability.

Results from the PCA indicate that water chemistry was not a major factor in accounting for the variation among sites. Most of the variability was explained by differences in alkalinity (*alk*), specific conductance (*spcond*), and other major inorganic ions (*CA*, *FE*, and *MG*) (fig. 8 and table 7). The first PCA axis (Nutrient) was strongly related to iron (*FE)*, specific conductance (*spcond*), nitrite plus nitrate (*NO2NO3*), and other intercorrelated variables (*CA, alk*, *residue*, *MG, and SO4)*. The second axis (Limestone) also was influenced by variables related to specific conductance, such as *NA*, *K*, *CL*, and phosphorus (*P, Pdis*, and *Portho*) levels; however, phosphorus levels at site 11 heavily influenced the interpretation. For example, the orthophosphorus (*Portho*) level at site 11 was 0.13 mg/L, whereas the median level for the other sites was only 0.02 mg/L. The elevated phosphorus levels were unexplained, yet were not considered to be related to cropland because of the low percentages of cropland in the basin.

The indirect gradient analysis revealed that the first PCA axis was significantly correlated with cropland density (fig. 9). Important variables, as aforementioned, were related to specific conductivity (*spcond*) and nutrients (*NO2NO3*) (Nutrient gradient). Nitrate (*NO2NO3*) was the only variable positively correlated with cropland density (fig. 9). The positive correlation between specific conductivity (*spcond*) and nitrate (*NO2NO3*) indicates that the more influence ground water has on streamflow, the more nitrate is likely to be present in the stream; thus, ground water could be transporting, rather than diluting, nitrate. The indirect gradient analysis of the second axis (Limestone gradient) did not show a clear correlation. The dominant variables (*NH4, NH4dis, NH4total, P, Pdis*, and *Portho*) indicate a strong nutrient influence; however, site scores from the second axis did not correlate with cropland density. The unexplained differences are presumed to be related to underlying natural gradients, such as elevation and geology, or to variables that were unaccounted for in the analysis.



Note: Site numbers are identified in table 1. Water-chemistry abbreviations are identified in table 3. Water-chemistry variables are represented by arrows and sites are represented by triangles. Sites and variables located near one another have similar characteristics and those located far apart have dissimilar characteristics. The length of the arrow indicates the relative importance of the variable to the axis. The location of the sites (based on site scores) along each ordination axis specifies the location of the site relative to the axis. Each axis is a linear combination of multiple variables.

Figure 8. Principal components analysis biplot illustrating the relation among water-chemistry variables for 11 sites in the Dissected Tablelands.

The small amount of variability explained by the ordination of the water chemistry data indicates that streams within the Dissected Tablelands are not greatly influenced by increases in cropland directly or are not accurately characterized based on the single base-flow sample. Detected differences between sites were related to specific conductance, which is expected because ground water is the primary source of streamflow during base-flow periods. The increased nitrite plus nitrate levels with increased cropland density indicates that nitrogen levels are influenced, to some degree, by cropland density.

Fish Communities

The fish-community data set for the Dissected Tablelands consists of a total of 7,586 individual fish (compared to 10,550 in the full EHR data set), representing 53 species (compared to 65 in the full EHR data set) in 11 families (compared to 15 in the full EHR data set) (table 8 and appendix 3). The cyprinids (minnows), percids (darters), and centrarchids (sunfish) were the most common groups of fishes. Nine species (largescale stoneroller, scarletfin shiner, striped shiner, longear sunfish, bluegill, banded sculpin, green sunfish, redline darter, and black darter) accounted for over 75 percent of individuals collected at Dissected Tablelands sites. One Federally threatened species, slackwater darter (*Etheostoma boschungi*), and one species of special concern, flame chub (*Hemitremia flammea*), also were collected and released during the survey. The largescale stoneroller (*Campostoma oligolepis*) was the most common species, making up 25 percent of the total abundance. Species from the full EHR data set not represented at sites in the

Table 7. Summary statistics from the principal components analysis of the water-chemistry variables for 11 sites in the Dissected Tablelands

[Variable abbreviations are listed in table 3; bolded variable loadings were considered important when absolute values were 0.2 or greater]

Water-chemistry variable	Variable loadings (see fig. 8)	
	Axis 1 Nutrient	Axis 2 Limestone
temp	0.11	**-0.22**
pH	**-0.20**	0.06
spcond	**-0.26**	0.16
alk	**-0.27**	0.15
NH4	0.16	**0.30**
NH4dis	0.18	**0.29**
NH4total	**0.20**	**0.25**
NO2NO3	**-0.21**	**0.22**
P	0.18	**0.29**
Pdis	0.18	**0.28**
Portho	0.16	**0.30**
DOC	**0.26**	0.12
turbid	**-0.21**	0.06
EC	**-0.20**	0.08
CA	**-0.26**	0.15
SIO2	-0.18	0.17
FE	**0.25**	0.09
K	**0.20**	**0.24**
NA	-0.03	**0.29**
CL	-0.17	**0.23**
MG	**-0.27**	0.14
MN	0.09	-0.13
SO4	**-0.24**	0.00
Eigenvalues	10.82	7.45
Percentage of variability in data set explained by axis.	45.07	31.03
Cumulative percentage of variability in data set explained by axis.	45.07	76.10

Dissected Tablelands were the freshwater drum (*Aplodinotus grunniens*), streamline chub (*Erimystax dissimilis*), northern studfish (*Fundulus catenatus*), brook silverside (*Labidesthes sicculus*), longnose gar (*Lepisosteus osseus*), ribbon shiner (*Lythrurus fumeus*), mountain shiner (*Lythrurus lirus*), bigeye shiner (*Notropis boops*), sauger (*Stizostedion canadense*), rainbow trout (*Oncorhynchus mykiss*), blackstripe topminnow (*Fundulus notatus*), and creek chubsucker (*Erimyzon oblongus*). Only one non-native species (redbreast sunfish, *Lepomis auritu*s) was collected, representing only 1 percent of the individual fish collected at the 11 sites in the Dissected Tablelands.

Ordination (CA) of the fish-community data resulted in two interpretable axes. Species along the first axis generally followed a lentic to lotic habitat (LowFlow gradient). Fishes at the lotic end of the gradient included the percids (ETHBLE, ETHRUF, and ETHFLA), cyprinids (CYPGAL, NOTTEL, NOTVOL, NOTRUB, CLIFUN, and NOTAMB), and centrarchids (AMBRUP and MICDOL) (fig. 10 and table 9). Fishes at the lentic end of the gradient included centrarchids (LEPGUL, LEPMIC, LEPMAC, and MICSAL), cyprinids (HEMFLA and RHIATR), and one each poecilid (GAMAFF), cyprinodontid (FUNOLI), and ictalurid (ICTPUN). Interpretation of the second axis (Percinids gradient) was not as clear but trended toward a gradient mixed with cyprinids (HEMFLA, RHIATR, CLIFUN) and centrarchids (MICDOL, LEPMIC, and LEPMAC) to percids (ETHBLE, ETHRUF, ETHSIM, and ETHKEN).

Slackwater Darter (*Etheostoma boschungi*), Federal Rank—Listed as Endangered. The slackwater darter is a Highland Rim endemic that is restricted to Highland Rim streams in and along the southern bend of the Tennessee River (Flint River, Shoal Creek, Limestone Creek, and Buffalo River). Usually found in the slower moving waters of pools, it is often associated with leaf litter and detritus and spawns in seasonally flooded or seepage areas of open fields (Boschung, 1976). (Photograph by J.R. Shute, Conservation Fisheries, Inc. Used with permission.)

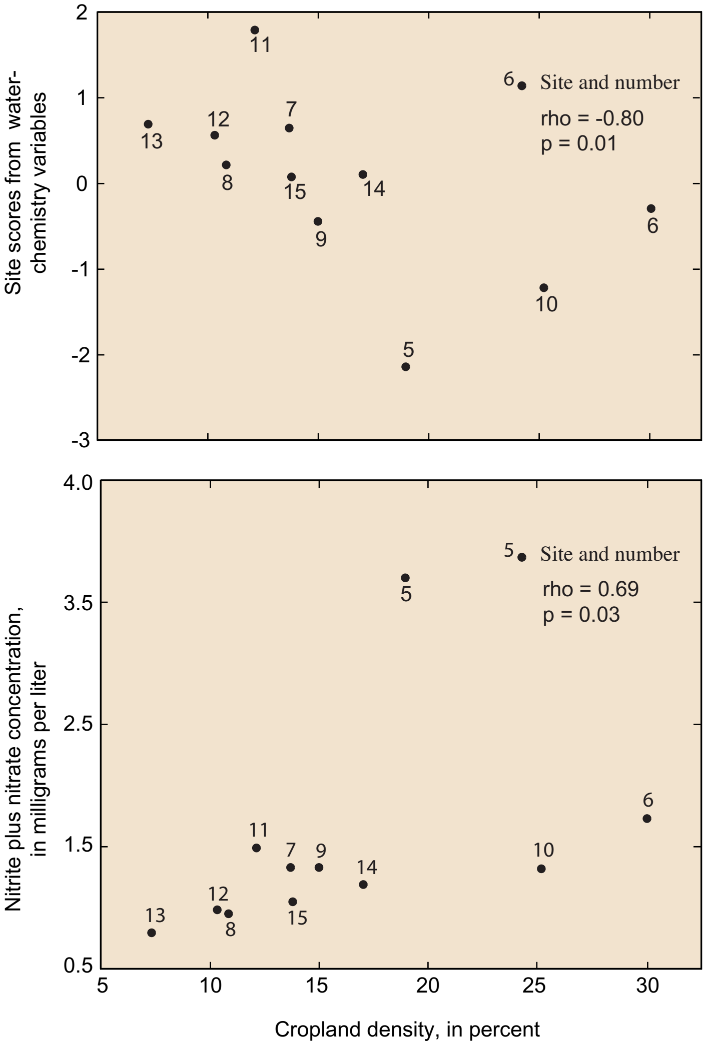


Figure 9. Comparison of cropland density to site scores from the first axis of the principal components analysis (water-chemistry variables) and to nitrate concentrations for 11 sites in the Dissected Tablelands. (Numbers represent site numbers shown in table 1.)

The most responsive community metrics were percentages of omnivores and stonerollers (*omnivores*), tolerant species (*tolerant*), specialized insectivores (*spinsect*), and simple lithophilic spawners (*simLiths*) (table 10). Ordination (PCA) of the 14 community metrics indicates that sites generally were influenced most by the number of species and the different feeding classes (fig. 11 and table 11). The first axis clearly displays a species diversity gradient, where the most important metrics were the number of native species (*natives*), number of darter species (*darters*), catch rate (*catchrate*), and percentages of fish as specialized insectivores (*spinsect*) and simple lithophilic spawners (*simLiths*). The intercorrelation among several of these metrics should be noted. For example, the majority of the percids also are classified as specialized insectivores and simple lithophilic spawners. The second axis appears to generally describe sites based along a habitat gradient. Sites 9, 10, and 6 at the "degraded" end of the gradient were associated with high percentages of tolerant species (*tolerant*), physical abnormalities (*anomalies*), and hybrids (*hybrid*), whereas sites 15, 13, 11, and 8 at the opposite end of the gradient were represented by high percentages of specialized insectivores (*spinsect*) and simple lithophilic spawners (*simLiths*). The most important metrics along the second axis were the number of darter species (*darters*) and percentages of individuals with abnormalities (*anomalies* and *DELT*), as tolerant species (*tolerant*) and as specialized insectivores (*spinsect*).

IBI scores ranged from 32 to 48 and had a mean score of 41 (table 11). The IBI was not designed to detect changes in fish communities caused by a single source or stressor. The IBI can at times detect these differences; however, the sensitivity of the analysis lies in the initial objective for which the scoring criteria were established—to provide a numerical value representing the integrity of the contributing basin and not to address causative factors. In most cases, the IBI is used as a means of ranking and priortizing watersheds based on a stream-health rating. The scores provided in this report simply serve as comparison to the CA and PCA and as a conservative approach to fish-community assessment.

Response of Fish Communities to Cropland Density and Natural Environmental Setting

Fish communities were summarized by CA, PCA, and IBI and were correlated with natural and anthropogenic factors to determine response of the fish communities to environmental differences associated with natural setting and cropland density. Because each summarization procedure possesses unique advantages and disadvantages, the manner in which the fish-community data set was summarized during each procedure is quite different. For example, the CA was summarized on the basis of individual taxa relative abundance, whereas the PCA was summarized on the basis of individual community metrics, which groups taxa having similar ecologic or taxonomic

Table 8. Fish species collected at 11 sites in the Dissected Tablelands

[*, non-native; **, Federally listed as "threatened"; ***, State listed as special concern; <, less than; (C), censored; species are listed in order of number of individuals collected; a complete list of all fishes collected at the 20 sites in the Eastern Highland Rim is given in appendix 3]

Common name	Scientific name	Species abbreviation	Number of sites with collections	Number of individuals collected	Relative abundance (percent)
Largescale stoneroller	*Campostoma oligolepis*	CAMOLI	11	1,926	25
Scarletfin shiner	*Lythrurus fasciolaris*	LYTARD	10	980	13
Striped shiner	*Luxilus chrysocephalus*	LUXCHR	11	625	8
Longear sunfish	*Lepomis megalotis*	LEPMEG	10	571	8
Bluegill	*Lepomis macrochirus*	LEPMAC	11	458	6
Banded sculpin	*Cottus carolinae*	COTCAR	10	394	5
Green sunfish	*Lepomis cyanellus*	LEPCYA	11	377	5
Redline darter	*Etheostoma rufilineatum*	ETHRUF	3	251	3
Black darter	*Etheostoma duryi*	ETHDUR	11	226	3
Northern hog sucker	*Hypentelium nigricans*	HYPNIG	11	180	2
Snubnose darter	*Etheostoma simoterum*	ETHSIM	6	161	2
Bigeye chub	*Notropis amblops*	NOTAMB	5	151	2
Rainbow darter	*Etheostoma caeruleum*	ETHCAE	8	138	2
Bluntnose minnow	*Pimephales notatus*	PIMNOT	9	115	2
Rock bass	*Ambloplites rupestris*	AMBRUP	6	94	1
Redbreast sunfish (C) *	*Lepomis auritus*	LEPAUR	3	90	1
Telescope shiner	*Notropis telescopus*	NOTTEL	1	90	1
Whitetail shiner	*Cyprinella galactura*	CYPGAL	4	80	1
Warmouth	*Lepomis gulosus*	LEPGUL	9	66	<1
Fantail darter	*Etheostoma flabellare*	ETHFLA	2	61	<1
Mimic shiner	*Notropis volucellus*	NOTVOL	2	60	<1
Slender madtom	*Noturus exilis*	NOTEXI	3	57	<1
Blackspotted topminnow	*Fundulus olivaceus*	FUNOLI	7	44	<1
Largemouth bass	*Micropterus salmoides*	MICSAL	10	42	<1
Western mosquitofish	*Gambusia affinis*	GAMAFF	5	40	<1
Greenside darter	*Etheostoma blennioides*	ETHBLE	3	38	<1
Golden redhorse	*Moxostoma erythrurum*	MOXERY	5	31	<1
Black redhorse	*Moxostoma duquesnei*	MOXDUQ	3	30	<1
Logperch	*Percina caprodes*	PERCAP	5	29	<1
Blackfin darter	*Etheostoma nigripinne*	ETHNIG	5	24	<1
Hybrid sunfish	*Lepomis* spp.	LEP_SP	5	18	<1
Yellow bullhead	*Ameiurus natalis*	AMENAT	7	13	<1
Redear sunfish	*Lepomis microlophus*	LEPMIC	5	13	<1
Black bullhead	*Ameiurus melas*	AMEMEL	1	13	<1
Flame chub ***	*Hemitremia flammea*	HEMFLA	2	11	<1
Spotted bass	*Micropterus punctulatus*	MICPUN	3	10	<1
Chain pickerel	*Esox niger*	ESONIG	3	10	<1
Blacknose dace	*Rhinichthys atratulus*	RHIATR	4	10	<1
Stripetail darter	*Etheostoma kennicotti*	ETHKEN	3	9	<1
Spotfin shiner	*Cyprinella spiloptera*	CYPSPI	9	9	<1
Least brook lamprey	*Lampetra aepyptera*	LAMAEP	4	7	<1
White sucker	*Catostomus commersoni*	CATCOM	3	6	<1
Unidentified lamprey (C)	*Ichthyomyzon* sp.	ICHsp	1	5	<1

Table 8. Fish species collected at 11 sites in the Dissected Tablelands—Continued

Common name	Scientific name	Species abbreviation	Number of sites with collections	Number of individuals collected	Relative abundance (percent)
Rosyface shiner	*Notropis rubellus*	NOTRUB	1	5	<1
Black crappie	*Pomoxis nigromaculatus*	POMNIG	1	4	<1
Spotted sucker	*Minytrema melanops*	MINMEL	3	3	<1
Dusky darter	*Percina sciera*	PERSCI	5	3	<1
Rosyside dace	*Clinostomus funduloides*	CLIFUN	2	2	<1
Creek chub	*Semotilus atromaculatus*	SEMATR	1	2	<1
Smallmouth bass	*Micropterus dolomieu*	MICDOL	1	1	<1
Channel catfish	*Ictalurus punctatus*	ICTPUN	1	1	<1
Spring cavefish	*Forbesichthys agassizi*	CHOAGS	1	1	<1
Slackwater darter **	*Etheostoma boschungi*	ETHBOS	1	1	<1
Creek chubsucker	*Erimyzon oblongus*	ERIOBL	1	1	<1
Total abundance				7,586	

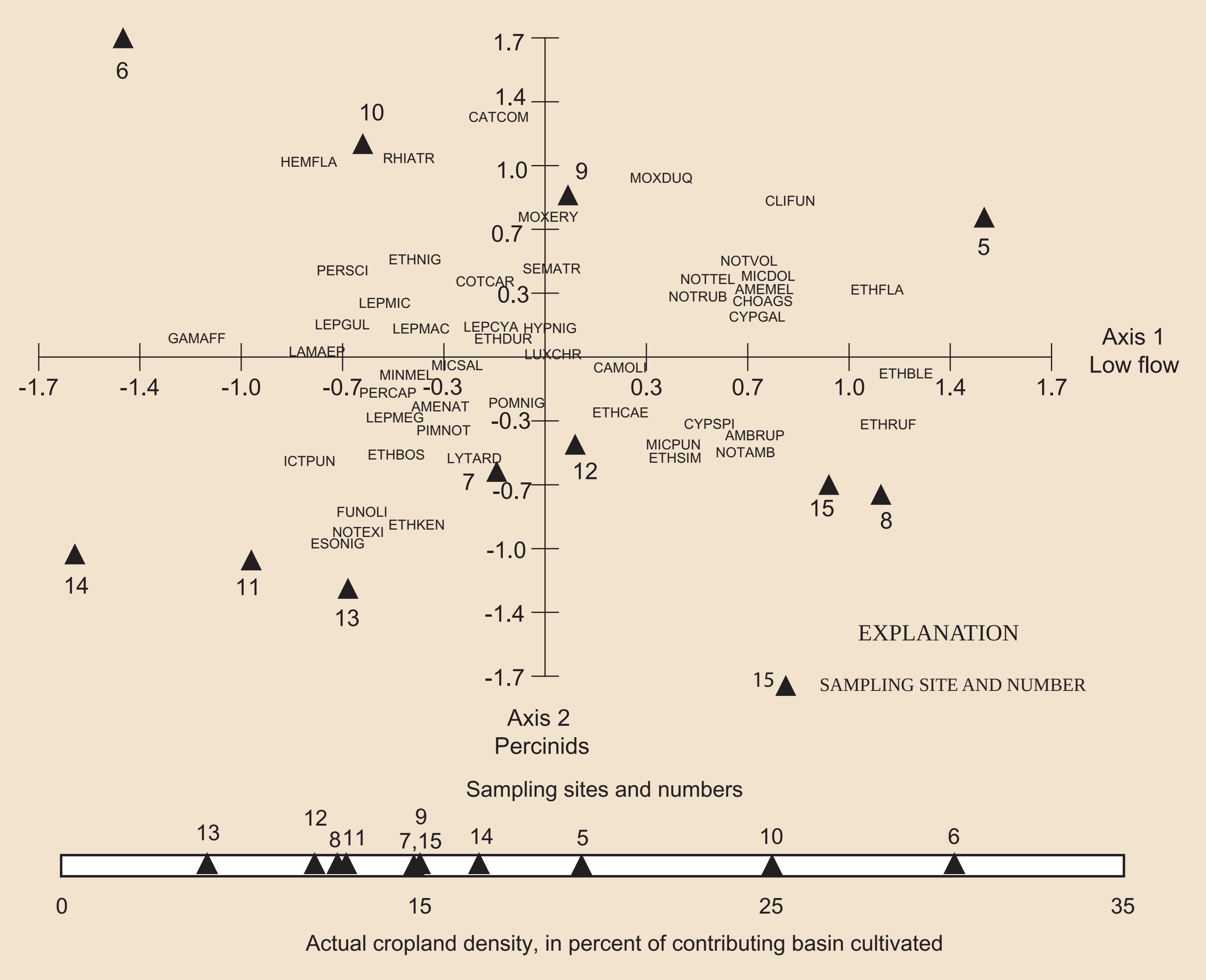


Figure 10. Correspondence analysis biplot illustrating the relation among fish abundances for 11 sites in the Dissected Tablelands.

Table 9. Summary statistics from the correspondence analysis of the fish-abundance data for 11 sites in the Dissected Tablelands

[Species abbreviations are listed in table 8; variable loadings listed for selected species]

Species abbreviation	Variable loadings (see fig. 10)	
	Axis 1 Low flow	Axis 2 Percinids
AMBRUP	0.78	-0.36
CAMOLI	0.34	-0.01
CATCOM	-0.09	1.35
CLIFUN	0.89	0.93
CYPGAL	0.80	0.28
CYPSPI	0.62	-0.31
ESONIG	-0.64	-0.90
ETHBLE	1.31	-0.06
ETHCAE	0.32	-0.26
ETHFLA	1.19	0.40
ETHKEN	-0.38	-0.85
ETHNIG	-0.39	0.56
ETHRUF	1.24	-0.31
ETHSIM	0.51	-0.44
FUNOLI	-0.59	-0.83
GAMAFF	-1.11	0.12
HEMFLA	-0.74	1.11
LEPGUL	-0.63	0.25
LEPMAC	-0.37	0.19
LEPMEG	-0.45	-0.22
LEPMIC	-0.49	0.36
LYTARD	-0.18	-0.52
MICPUN	0.52	-0.48
MICSAL	-0.27	0.02
MINMEL	-0.39	-0.03
MOXDUQ	0.47	1.02
MOXERY	0.07	0.85
NOTAMB	0.73	-0.38
NOTEXI	-0.58	-0.96
NOTTEL	0.80	0.44
NOTVOL	0.76	0.40
PERCAP	-0.48	-0.11
PERSCI	-0.63	0.51
RHIATR	-0.42	1.11
SEMATR	0.09	0.50
Eigenvalues	0.22	0.15
Percentage of variability in data set explained by axis	26.24	17.77
Cumulative percentage of variability in data set explained by axis	26.24	44.00

Table 10. Summary statistics from the principal components analysis of the community metrics for 11 sites in the Dissected Tablelands

[Metric abbreviations are listed in table 4; bolded variable loadings were considered important when absolute values were greater than 0.30]

Species	Variable loadings (see fig. 11)	
	Axis 1 Species diversity	Axis 2 Habitat
natives	**0.43**	-0.12
omnivores	0.25	0.12
darters	**0.32**	**-0.33**
anomalies	0.28	**0.34**
sunfish	-0.18	-0.25
suckers	0.08	0.29
intols	**0.32**	0.05
tolerant	0.23	**0.40**
spinsect	0.17	**-0.40**
pisc	0.09	-0.28
catchrate	**0.37**	-0.13
hybrid	-0.13	0.24
simLiths	0.28	-0.23
DELT	**0.34**	0.27
Eigenvalues	4.31	3.71
Percentage of variability in data set explained by axis.	30.80	26.48
Cumulative percentage of variability in data set explained by axis.	30.80	57.29

Table 11. Summary of fish-community metrics and Index of Biological Integrity scores for 11 sites in the Dissected Tablelands

[Full site names are listed in table 1; metrics reported here are presumed indicators of anthropogenic disturbance; see appendix 4 for species tolerances, feeding guilds, and other species classifications; metric abbreviations are shown in table 4; *, denotes metrics used in Index of Biological Integrity calculation]

Site abbreviation	Site number	Community metric														
		*natives**	*omnivores**	*darters**	*anomalies**	*sunfish**	*suckers**	*intols**	*tolerant**	*spinsect**	*pisc**	*catchrate**	*hybrid**	*simLiths*	*DELT*	IBI
Beans	5	28	35.6	6	2.3	3	4	5	16.2	40.4	1.1	49	0.0	44.1	0.7	46
Bdam	6	19	4.1	3	0.5	5	2	0	13.2	9.1	0.5	14	1.0	17.3	0.1	34
BrierF	7	23	37.1	4	1.1	6	3	1	6.1	20.0	2.5	49	1.3	25.3	0.5	40
FlintLin	8	26	54.8	8	0.6	5	2	1	9.7	32.5	2.3	95	0.0	34.0	0.5	44
Hester	9	25	46.9	4	23.1	4	3	2	36.4	14.3	1.3	61	0.7	44.7	1.9	32
Indian	10	19	31.1	2	0.5	5	5	1	14.8	4.3	1.0	28	0.0	25.8	0.2	38
Lime	11	22	18.2	4	0.5	6	1	0	11.4	50.8	1.9	27	0.2	54.2	0.3	42
LitLim	12	19	59.6	3	0.4	4	1	2	12.7	17.5	3.2	43	0.2	27.7	0.1	36
Piney	13	23	11.6	6	1.8	5	2	1	11.9	52.6	0.5	51	0.0	55.3	0.2	48
RndIs	14	20	4.0	3	0.9	4	1	1	9.9	29.2	0.9	27	0.0	30.4	0.5	38
Wfork	15	25	20.6	7	0.6	6	1	2	5.3	40.2	6.7	57	0.0	46.9	0.4	48

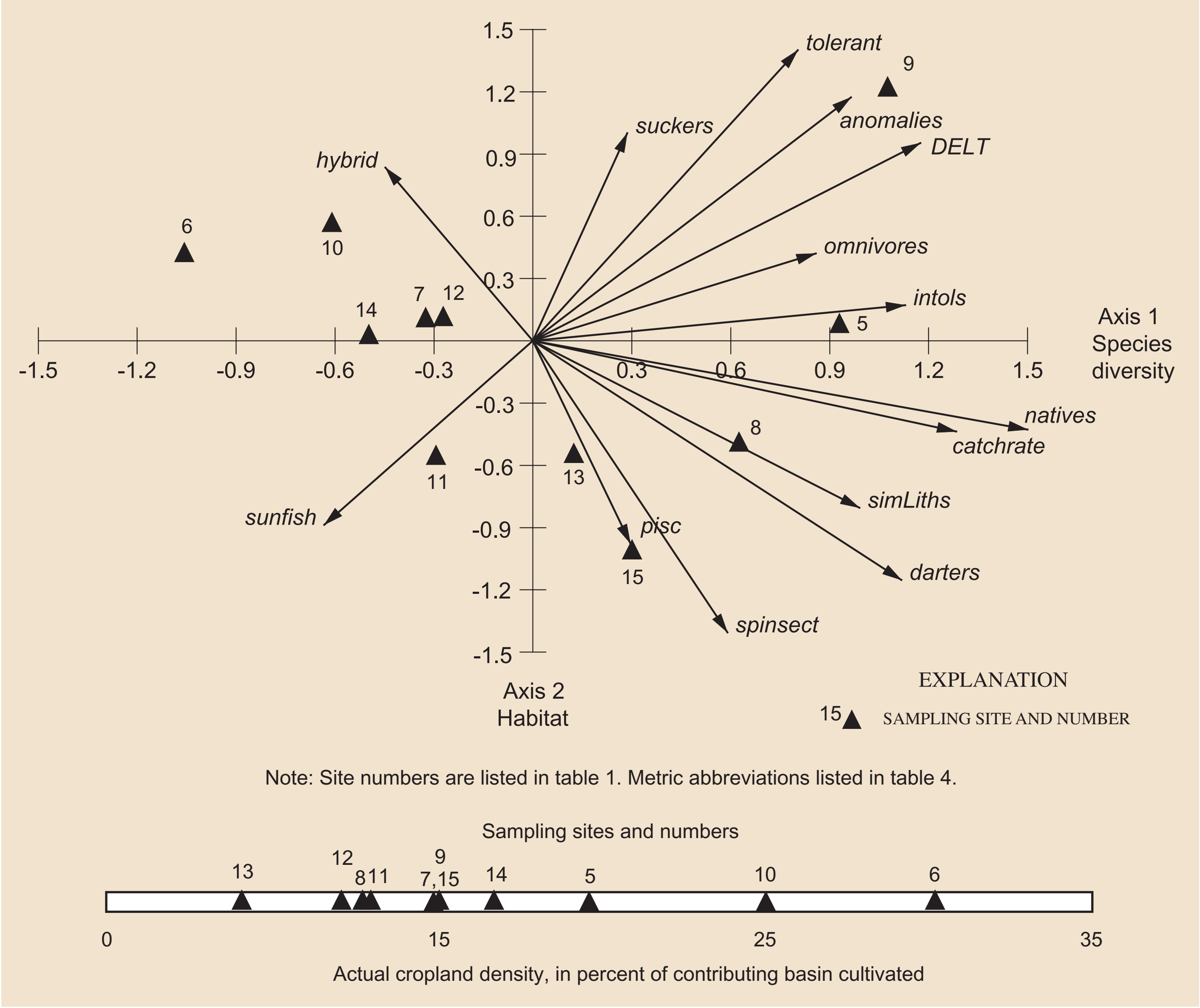


Figure 11. Principal components analysis biplot illustrating the relation among fish-community metrics for 11 sites in the Dissected Tablelands.

characteristics. The IBI, which is probably the most conservative of these three procedures, summarizes fish-community data and calculates a numeric score based on 12 community metrics. Recognizing these fundamental differences, all three procedures detected differences related to HHL quality; however, only the CA indicated that these differences were significantly correlated with cropland density. None of the procedures indicated a statistically significant response to water chemistry.

Ordination of the HHL variables identified land use as the dominant gradient at sites in the Dissected Tablelands; however, the indirect gradient analysis of CA site scores along with HHL variables indicates that fish communities were affected slightly more by streamflow and elevation than by land use (table 12). The indirect gradient analysis of site scores from CA axis 1, which was described as the flow gradient, with streamflow and elevation suggests some darter (ETHRUF, ETHBLE, and ETHFLA) and minnow (CAMOLI, NOTVOL, and CYPGAL) species prefer sites at higher elevations and sustained streamflows (table 12 and fig. 10). As streamflow and elevation decrease, sunfish (LEPGUL, LEPMAC, LEPMEG, MICSAL, and LEPMIC), topminnows (FUNOLI), and livebearers (GAMAFF) were more common. Darters

Table 12. Summary of indirect gradient analysis relating site scores from the correspondence analysis and principal components analysis of the fish-community data to selected habitat, hydrology, and land-use variables for 11 sites in the Dissected Tablelands

[Bolded p-values significant at $p<0.05$. See table 2 for description of environmental variable descriptions and table 4 for description of fish-community metrics; CA, correspondence analysis of fish-community data; PCA, principal components analysis of community metric data; IBI, Index of Biological Integrity]

Environmental variable abbreviation	Correlation coefficient (ρ) and statistical significance									
	Site scores from CA (relative abundance) (see fig. 10)				Site scores from PCA (individual metrics) (see fig. 11)				IBI (Integrated metrics)	
	Axis 1 Low flow		Axis 2 Percinids		Axis 1 Species diversity		Axis 2 Habitat			
	ρ	p-value	ρ	p-value	ρ	p-value	ρ	p-value	ρ	p-value
elevation	0.72	0.024	-0.01	0.954	0.67	**0.037**	0.29	0.372	0.27	0.393
DA	0.29	0.365	-0.10	0.741	0.33	0.308	0.21	0.518	0.57	0.070
pasture	0.23	0.464	-0.71	**0.039**	0.46	0.147	-0.15	0.615	0.36	0.361
BFwidth	0.20	0.537	-0.69	**0.027**	0.54	0.093	-0.10	0.741	0.39	0.225
embedded	-0.41	0.190	0.71	**0.025**	-0.85	**0.007**	0.17	0.592	-0.68	**0.030**
LowBaseQ	0.78	**0.010**	0.26	0.413	0.50	0.117	0.29	0.365	0.22	0.497
gradient	0.41	0.195	-0.42	0.176	0.54	0.089	0.06	0.863	0.32	0.314
cobble	0.49	0.122	0.12	0.707	0.16	0.633	0.16	0.623	0.04	0.899
beefcow	0.66	**0.037**	-0.47	0.131	0.78	**0.014**	0.23	0.481	0.59	0.060
cropland	-0.20	0.518	0.72	**0.024**	-0.50	0.111	0.14	0.677	-0.40	0.204

(ETHKEN, ETHNIG, PERSCI, and PERCAP) and minnows (LYTARD and PIMNOT) were found at low-elevation streamflow sites but were represented by a somewhat different group of species that possibly are more tolerant of low sustained streamflows. Streams with unstable streamflows support fish communities that are more likely to recover quickly from disturbance than do streams with more predictable flows (Poff and Ward, 1990). Dispersion of site scores along CA axis 2 were not as great as along the CA axis 1, which means less variability existed between sites (fig. 10). The positive correlation between axis 2 and cropland density, and the negative correlation with pasture suggests that several sucker and minnow species preferred, or were more tolerant of, increases in cropland and substrate embeddedness. Although the abundance of some species increased as percentages of pasture and numbers of beef cows increased, fishes actually may be responding positively to a lack of disturbance. For example, although numbers of beef cows generally increased with the amount of pastureland, the maximum number of cows per acre was low at about four cows per acre. This suggests that pastures are not being overgrazed, and more importantly, pastures are either lying dormant or primarily are being used for hay production, which does not seem to pose a severe negative impact on fishes.

The indirect gradient analysis of the PCA site scores based on the community metrics suggests that community metrics were slightly less responsive to environmental characteristics related to natural setting or cropland density when compared to CA site scores. Site scores from the first PCA axis were negatively correlated with substrate embeddedness and positively correlated with elevation and numbers of beef cows, indicating that some community metrics responded negatively to cropland density (table 12). Sites 5, 8, and 9 at the upper end of the Low flow gradient contained high numbers of individuals and had the highest species diversity of the sites in the Dissected Tablelands, yet also had high percentages of abnormalities. Sites 6, 10, and 14 at the low end of the gradient contained high numbers of sunfish species and slightly more hybrids. The Habitat axis was not significantly correlated with any of the community metrics (fig. 11).

The IBI, as expected, provided similar results as the PCA of the individual metrics. However, because metrics were integrated into a single score, the scores were less sensitive to change in natural setting and cropland density. For example, the only HHL variable directly correlated with IBI scores was substrate embeddedness, which suggests that the effects from natural setting or cropland density may be obscured by the integration of metrics.

Although the intent of this report is not to develop specific criteria, such as community metrics or individual taxa, for modeling changes in cropland density or natural environmental setting, generally summarizing how individual community metrics directly responded to cropland density and the environmental gradients deemed most important by the indirect gradient analysis is beneficial. By performing an indirect gradient analysis that correlates site scores from the PCA of the environmental data to community metrics, the variability due to complex instream processes may be minimized and transferred to a more interpretable set of environmental variables and fish-community characteristics. The results could therefore be used as an ecologically based management tool that demonstrates how certain community metrics (in stream basins about 30 to 100 square miles located in the Dissected Tablelands) generally will respond to changes in cropland allotments and streamflow-altering perturbations.

The indirect gradient analysis of 13 community metrics revealed that the percentage of specialized insectivores was the only metric that was significantly correlated with the land-use gradient (table 13). Other metrics responded similarly, but correlations were not statistically significant at $p<0.05$ (fig. 12). This indicates that increases in cropland density directly affect fishes that require clean substrates to successfully feed and reproduce. Substrate embeddedness not only

Table 13. Summary of indirect gradient analysis relating site physical and water-chemistry data scores from the principal components analysis and cropland density to fish-community metrics for 11 sites in the Dissected Tablelands

[Bolded p-values significant at $p<0.05$. See table 4 for description of fish-community metrics; PCA, principal components analysis of community metric data; HHL, habitat, hydrology, and land use]

Community metric abbreviation	Correlation coefficient (ρ) and statistical significance									
	Site Scores from PCA (HHL data) (see fig. 6)				Site scores from PCA (water-chemistry data) (see fig. 8)				Cropland density	
	Axis 1 Land use		Axis 2 Streamflow		Axis 1 Nutrient		Axis 2 Limestone			
	ρ	p-value	ρ	p-value	ρ	p-value	ρ	p-value	ρ	p-value
natives	0.41	0.195	0.54	0.088	-0.15	0.610	-0.16	0.610	-0.18	0.560
anomalies	-0.03	0.908	0.51	0.107	-0.23	0.476	-0.17	0.581	0.02	0.954
sunfish	0.01	0.976	-0.39	0.208	0.53	0.100	-0.21	0.500	-0.22	0.472
DELT	0.01	0.988	0.34	0.294	-0.29	0.344	-0.17	0.590	0.12	0.715
tolerant	0.15	0.635	-0.39	0.211	0.37	0.244	-0.54	0.087	-0.40	0.201
darters	0.62	**0.051**	0.42	0.191	0.17	0.597	-0.27	0.379	-0.45	0.146
simLiths	0.51	0.111	0.46	0.147	0.29	0.365	0.01	0.998	-0.50	0.111
spinsect	0.64	**0.046**	0.27	0.396	0.49	0.124	-0.06	0.829	-0.55	0.077
omnivores	0.50	0.117	-0.01	0.966	-0.06	0.829	-0.01	0.966	-0.35	0.256
catchrate	0.51	0.112	0.34	0.285	-0.04	0.885	-0.41	0.189	-0.45	0.153
pisc	0.46	0.154	-0.45	0.154	0.21	0.517	-0.35	0.267	-0.40	0.200
intols	0.24	0.463	0.18	0.582	-0.47	0.135	-0.19	0.532	-0.04	0.879
suckers	-0.32	0.300	0.41	0.20	-0.57	0.070	0.33	0.304	0.43	0.175
hybrid	-0.27	0.388	-0.25	0.424	0.21	0.518	0.22	0.488	0.06	0.849

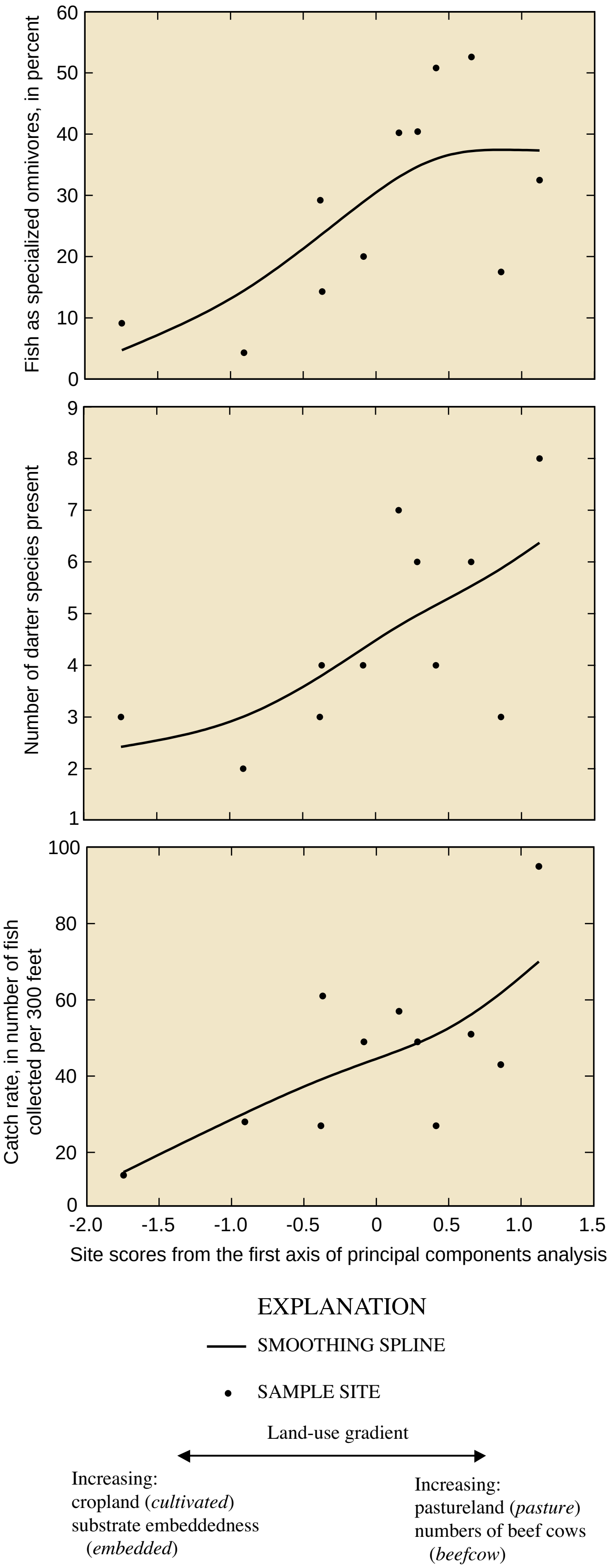


Figure 12. Response of selected fish-community metrics to site scores from axis 1 of the principal components analysis.

affects species that feed by browsing, grazing, filtering, and stalking but also may directly affect aquatic invertebrates and periphyton, which the fish eat. Berkman and Rabeni (1987) also showed that sediment was detrimental to insectivores, herbivores, and lithophils in Missouri streams. The streamflow gradient, which was primarily interpreted as differences in elevation and steamflow, also could have negative implications on several community metrics (*natives*, *anomalies*, and *simLiths*). Although correlations were not statistically significant at $p<0.05$, the positive correlation between streamflow and numbers of native species, percentages of abnormalities and simple lithophilic spawners could be used to better manage streamflow during low hydrologic periods. For example, decisions concerning the permitting of instream habitat-altering practices and water withdrawals might be based on a 7-day 10-year low flow (7Q10), which highlights the potential vulnerability of some Federally listed fishes. Because a large number of Federally listed species in the LTEN are classified as simple lithophilic spawners, the affects of removing water from a stream that already has a low base flow during drier periods ultimately could jeopardize the existence of some sensitive species. The lack of response of the omnivore and stoneroller metric, which is sometimes anecdotally used to indicate changes in nutrient levels from agricultural sources, was unexpected. In other studies, increases in stoneroller percentages have been associated with increases in nutrient levels from agricultural activities and general habitat degradation (Power and Mathews, 1983; Maret, 1997; Petersen, 1998).

Species like the fantail darter (*Etheostoma flabellare*), stripetail darter (*E. kennicotti*), and blackfin darter (*E. nigripinne*) are members of the group of fishes known as Catonotus. These fishes are highly sensitive to sedimentation because they physically attach their eggs to the undersides of rocks. As sediment fills crevices and voids in the substrate, suitable nesting sites are difficult to locate. (Photograph by B.M. Burr and L.M. Page, Southern Illinois University and University of Florida, respectively. Used with permission.)

Although the stoneroller was the most abundant fish in the Dissected Tablelands, abundances did not respond to changes in nutrients or cropland density. Stonerollers generally were more sensitive to changes in reach gradient, substrate size, and streamflow; they prefer high gradients, cobble-size substrate, and a high baseflow.

CONCLUSIONS

The purpose of this study was to identify the primary environmental characteristics that influence fish-community structure in the Eastern Highland Rim of the lower Tennessee River Basin. Minimizing natural variability enhances our ability to detect differences caused by agricultural factors. However, fish communities within the Eastern Highland Rim are influenced more by natural factors, such as streamflow and elevation, than by factors associated with percentages of cropland. Although ecoregions are defined as geographic areas with homogeneous biological communities and terrestrial characteristics (soils, vegetation, climate, geology, physiography), ecoregion boundaries should not always be “flatly” accepted because of the heterogeneous nature of rivers and physiographic regions. Based on the indirect gradient analysis, sites were subdivided into the Moulton Valley, the Dissected Tablelands, and the Barrens to further minimize natural variability.

Elevation and streamflow, followed by land use, were the most important gradients that influenced fish-community structure at the 11 sites of the Dissected Tablelands subgroup and in the 20 sites in the Eastern Highland Rim. Substrate embeddedness was correlated negatively with the second correspondence analysis axis and several community metrics, indicating that most fishes in the Dissected Tablelands require clean substrates to successfully feed and reproduce. Embeddedness not only inhibits feeding behavior but also directly affects food availability. Even though sedimentation is one of the most common pollutants to aquatic systems, differentiating anthropogenic sources from natural sources is difficult.

Although a large amount of literature exists relating agriculture and the damaging effects of sediment on stream fishes in western streams, such studies have been limited in the Southeast, which supports the most diverse and also the most imperiled aquatic fauna in North America. Research has primarily focused on a select number of species and failed to address the effects of sediment on entire fish communities. The analysis presented here documents that fish communities in the Dissected Tablelands respond negatively to increases in substrate embeddedness and further documents that embeddedness correlates positively to cropland density. However, to suggest that fish-community degradation is related directly to cropland density, in all cases, would be premature. For example, the reason intensively cultivated areas are located along river bottoms and not along the ridges is because of the deep, fertile soils associated with alluvial deposits along river terraces. In this case, embeddedness could be the result of natural processes, where erosion is accelerated by cultivation. Alternatively, the embeddedness gradient among sites in the Dissected Tablelands may be in response to historical or transitional land use rather than to the present cropland-density gradient. The watersheds of Beaverdam Creek and Indian Creek in the Eastern Highland Rim that were among the most embedded of all sites in the Dissected Tablelands have been intensively cultivated, but within the last 5 to 10 years, these two sites have undergone a transition from crop to residential land use. The observed embeddedness could be the result of historical land uses or more recent land disturbances, such as residential construction. Alternatively, Hester Creek and Beans Creek, which also are heavily embedded, drain predominately agricultural areas that have not undergone any land-use changes over the last 20 years. Whatever the source of sediment, fish communities are impaired as sedimentation and embeddedness increase.

Although a distinct response threshold was not identified in this study, fish communities were affected negatively by increases of cropland density in the Dissected Tablelands. Other studies have documented a threshold response when basins approach 50-percent cultivation. Future methods for monitoring changes at the ecoregion scale should consider variation in natural setting as well as the variety of stressors associated with agriculture. For example, methods applicable in the corn-belt region of the Midwest probably will not be effective for detecting changes in fish communities downstream from confined animal feeding operations or downstream from small patches of land cultivated for cotton and soybeans in the Southeast. The challenge now is in selecting a relevant suite of fish indicators that will respond to a full range of land-use changes. Community-level indicators, therefore, should be tailored to address individual problems and should not function as a remedy for all types of landscape disturbances. The techniques presented in this report should prove useful in narrowing the suitable list of candidate fish-community metrics and in establishing predictive criteria for streams in the Eastern Highland Rim.

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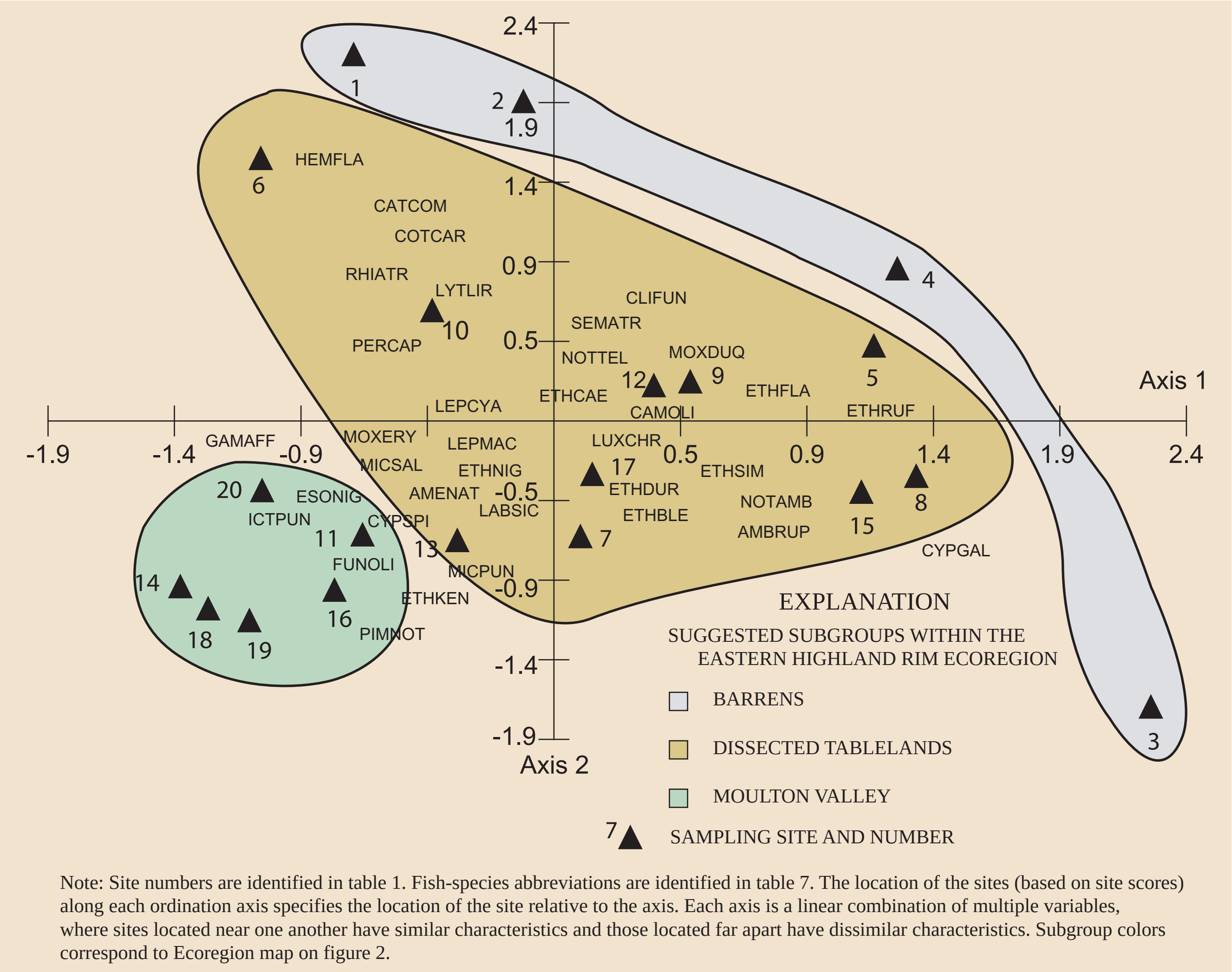
APPENDIXES

Appendix 1. Summary of indirect gradient analysis relating site scores from the correspondence analysis and principal components analysis of the fish-community data to selected habitat, hydrology, and land-use variables for 20 sites in the Eastern Highland Rim Ecoregion

[p-values significant at p<0.05; See table 2 for environmental variable descriptions and table 4 for description of fish-community metrics; CA, correspondence analysis; p=Spearman’s rho; ---, not statistically significant]

Environmental variable abbreviation	**Correlation coefficient (ρ) and statistical significance**											
	CA axes				**Fish-community metrics**							
	CA 1		**CA 2**		**omnivores**		**spinsect**		**catchrate**		**simLiths**	
	ρ	**p-value**	ρ	**p-value**	ρ	**p-value**	ρ	**p-value**	ρ	**p-value**	ρ	**p-value**
elevation	0.64	0.005	---	---	---	---	0.54	0.018	---	---	0.47	0.042
opencanopy	0.53	0.020	---	---	---	---	---	---	---	---	---	---
embedded	-0.48	0.036	---	---	---	---	-0.59	0.010	---	---	-0.56	0.015
LowBaseQ	0.61	0.008	0.54	0.019	---	---	---	---	---	---	---	---
depth	---	---	0.49	0.032	---	---	---	---	---	---	---	---
cobble	---	---	---	---	0.71	0.002	---	---	---	---	---	---
cropland density	---	---	---	---	---	---	---	---	---	---	---	---



Note: Site numbers are identified in table 1. Fish-species abbreviations are identified in table 7. The location of the sites (based on site scores) along each ordination axis specifies the location of the site relative to the axis. Each axis is a linear combination of multiple variables, where sites located near one another have similar characteristics and those located far apart have dissimilar characteristics. Subgroup colors correspond to Ecoregion map on figure 2.

Appendix 2. Correspondence analysis biplot illustrating the relation among fish communities for 20 sites in the Eastern Highland Rim Ecoregion.

Appendix 3. Fish species and the number of individuals collected at 20 sites in the Eastern Highland Rim Ecoreigon

[Station identification numbers are listed in table 1]

Family	Common name	Scientific name	Site number																			
			1	**2**	**3**	**4**	**5**	**6**	**7**	**8**	**9**	**10**	**11**	**12**	**13**	**14**	**15**	**16**	**17**	**18**	**19**	**20**
Amblyopsidae	Spring cavefish	*Chologaster agassizi*	0	0	0	0	1	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Atherinidae	Brook silverside	*Labidesthes sicculus*	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	5	1	0	0	0
Catostomidae	White sucker	*Catostomus commersoni*	2	1	0	0	4	1	0	0	0	1	0	0	0	0	0	0	0	0	0	0
	Creek chubsucker	*Erimyzon oblongus*	0	0	0	0	0	0	0	0	1	0	0	0	0	0	0	0	0	0	0	0
	Northern hog sucker	*Hypentelium nigricans*	4	11	7	9	26	4	10	19	21	31	2	13	24	4	26	4	3	2	4	1
	Spotted sucker	*Minytrema melanops*	0	0	0	4	0	0	1	0	0	1	0	0	1	0	0	0	0	0	1	8
	Black redhorse	*Moxostoma duquesnei*	0	0	0	4	9	0	0	0	19	2	0	0	0	0	0	0	5	0	0	0
	Golden redhorse	*Moxostoma erythrurum*	0	1	0	0	3	0	1	1	10	16	0	0	0	0	0	0	3	3	1	2
Centrarchidae	Rock bass	*Ambloplites rupestris*	0	1	53	0	9	0	2	27	0	0	1	20	0	0	35	1	10	0	0	4
	Redbreast sunfish	*Lepomis auritus*	0	0	0	0	0	0	0	0	0	6	0	0	68	16	0	0	0	0	0	0
	Green sunfish	*Lepomis cyanellus*	7	25	0	23	83	13	8	20	97	24	37	29	32	24	10	23	3	19	16	9
	Warmouth	*Lepomis gulosus*	2	2	0	2	0	15	4	2	3	6	5	0	1	20	10	2	1	5	0	0
	Bluegill	*Lepomis macrochirus*	44	26	3	99	2	30	57	24	62	109	13	10	20	74	57	61	6	48	24	7
	Longear sunfish	*Lepomis megalotis*	66	1	0	9	0	20	99	47	14	39	50	23	58	167	54	42	95	214	110	25
	Redear sunfish	*Lepomis microlophus*	0	0	0	0	0	2	0	0	0	3	3	0	1	0	4	2	1	1	0	0
	Hybrid sunfish	*Lepomis* spp.	0	0	0	0	0	2	6	0	7	0	1	2	0	0	0	3	1	0	2	0

Appendix 3. Fish species and the number of individuals collected at 20 sites in the Eastern Highland Rim Ecoreigon—Continued

Family	Common name	Scientific name	Site number																			
			1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20
Centrarchidae (cont.)	Smallmouth bass	*Micropterus dolomieu*	0	0	0	0	1	0	0	0	0	0	0	0	0	0	0	0	4	0	0	0
	Spotted bass	*Micropterus punctulatus*	0	0	0	0	0	0	1	0	0	0	0	4	0	0	5	1	3	1	4	2
	Largemouth bass	*Micropterus salmoides*	1	0	0	0	0	1	5	6	13	4	2	1	2	5	3	2	0	6	0	0
	Black crappie	*Pomoxis nigromaculatus*	0	0	0	0	0	0	4	0	0	0	0	0	0	0	0	0	0	0	0	0
Cottidae	Banded sculpin	*Cottus carolinae*	111	58	0	5	75	64	0	20	72	11	36	78	9	1	28	0	2	0	0	3
Cyprinidae	Largescale stoneroller	*Campostoma oligolepis*	6	45	30	129	259	3	152	670	180	85	32	411	25	3	106	3	90	19	9	2
	Rosyside dace	*Clinostomus funduloides*	0	27	0	0	1	0	0	0	1	0	0	0	0	0	0	0	0	0	0	0
	Whitetail shiner	*Cyprinella galactura*	0	0	65	0	6	0	0	7	48	0	0	0	0	0	19	0	0	0	0	0
	Spotfin shiner	*Cyprinella spiloptera*	0	2	0	0	0	0	0	9	0	0	0	0	0	0	0	1	8	18	7	0
	Streamline chub	*Erimystax dissimilis*	1	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
	Flame chub	*Hemitremia flammea*	9	2	0	0	0	10	0	0	1	0	0	0	0	0	0	0	0	0	0	0
	Striped shiner	*Luxilus chrysocephalus*	0	3	3	1	48	4	20	111	248	32	19	75	41	5	22	2	81	5	0	0
	Scarletfin shiner	*Lythrurus fasciolaris*	0	1	29	1	46	1	44	121	63	0	245	83	153	144	80	18	11	20	7	0
	Ribbon shiner	*Lythrurus fumeus*	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	4
	Mountain shiner	*Lythrurus lirus*	1	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
	Bigeye chub	*Notropis amblops*	0	0	0	0	2	0	31	95	3	0	0	0	0	0	20	0	0	0	0	0

Appendix 3. Fish species and the number of individuals collected at 20 sites in the Eastern Highland Rim Ecoreigon—Continued

Family	Common name	Scientific name	Site number																			
			1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20
Cyprinidae (cont.)	Bigeye shiner	*Notropis boops*	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	43	0	0	0
	Rosyface shiner	*Notropis rubellus*	0	0	0	0	5	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
	Telescope shiner	*Notropis telescopus*	0	0	0	0	90	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
	Mimic shiner	*Notropis volucellus*	0	0	0	0	59	0	0	0	0	0	0	0	0	1	0	0	28	0	0	0
	Bluntnose minnow	*Pimephales notatus*	0	0	2	0	2	0	3	15	22	3	53	0	5	10	2	0	0	23	62	1
	Blacknose dace	*Rhinichthys atratulus*	0	0	0	0	0	1	0	0	7	1	0	1	0	0	0	0	0	0	0	0
	Creek chub	*Semotilus atromaculatus*	0	2	0	0	0	0	0	0	2	0	0	0	0	0	0	0	0	0	0	0
Fundulidae	Northern studfish	*Fundulus catenatus*	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	1	0	0	0
	Blackstripe topminnow	*Fundulus notatus*	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
	Blackspotted topminnow	*Fundulus olivaceus*	0	0	0	0	0	0	4	1	0	0	8	4	6	20	1	5	5	4	3	3
Ictaluridae	Black bullhead	*Ameiurus melas*	1	0	0	0	13	0	0	0	0	0	0	0	0	0	0	12	0	0	0	0
	Yellow bullhead	*Ameiurus natalis*	0	0	0	0	0	0	1	0	5	1	1	0	1	2	2	1	1	1	0	1
	Channel catfish	*Ictalurus punctatus*	0	0	0	0	0	0	0	0	0	0	0	0	0	1	0	0	0	1	0	0
	Slender madtom	*Noturus exilis*	0	0	0	0	0	0	0	0	0	0	0	6	48	3	0	6	0	2	0	0
Lepisosteidae	Longnose gar	*Lepisosteus osseus*	0	0	0	1	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Esocidae	Chain pickerel	*Esox niger*	0	0	0	0	0	0	0	0	0	0	8	1	1	0	0	0	0	0	0	1
Percidae	Greenside darter	*Etheostoma blennioides*	0	0	0	0	15	0	0	13	0	0	0	0	0	0	10	1	15	0	5	0

Appendix 3. Fish species and the number of individuals collected at 20 sites in the Eastern Highland Rim Ecoreigon—Continued

Family	Common name	Scientific name	Site number																			
			1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20
Percidae (cont.)	Slackwater darter	*Etheostoma boschungi*	0	0	0	0	0	0	0	0	0	0	1	0	0	0	0	0	0	0	0	0
	Rainbow darter	*Etheostoma caeruleum*	43	50	0	11	17	0	1	24	28	0	15	27	14	0	12	0	21	0	0	1
	Black darter	*Etheostoma duryi*	23	7	120	50	37	12	5	16	29	6	27	25	48	2	19	27	22	5	43	1
	Fantail darter	*Etheostoma flabellare*	0	0	0	0	56	0	0	0	0	0	0	0	0	0	5	0	1	0	0	0
	Stripetail darter	*Etheostoma kennicotti*	0	0	0	0	0	0	0	0	0	0	5	0	0	1	3	4	3	4	0	0
	Blackfin darter	*Etheostoma nigripinne*	0	0	1	0	0	4	7	1	11	0	0	0	1	0	0	2	1	1	5	0
	Redline darter	*Etheostoma rufilineatum*	0	0	0	156	25	0	0	143	0	0	0	0	0	0	83	0	0	0	0	0
	Snubnose darter	*Etheostoma simoterum*	0	0	0	0	17	0	7	56	4	0	0	0	51	0	26	0	1	1	0	0
	Logperch	*Percina caprodes*	23	15	0	1	0	0	0	2	0	11	0	2	11	3	0	0	8	4	6	1
	Dusky darter	*Percina sciera*	0	0	0	0	0	1	0	1	0	0	0	0	1	0	0	0	0	0	2	0
	Sauger	*Stizostedion canadense*	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	2
Petromyzontidae	Unidentified lamprey	*Ichthyomyzon* sp.	3	0	0	0	5	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
	Least brook lamprey	*Lampetra aepyptera*	0	0	0	0	0	1	1	0	0	0	4	1	0	0	0	0	0	0	0	0
Poeciliidae	Western mosquitofish	*Gambusia affinis*	0	0	0	0	0	8	0	1	1	0	9	0	0	21	0	0	0	0	1	2
Salmonidae	Rainbow trout	*Oncorhynchus mykiss*	0	2	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Scianidae	Freshwater drum	*Aplodinotus grunniens*	0	0	0	1	0	0	0	0	0	0	0	0	0	0	0	0	0	1	0	1

Appendix 4. Fish species, tolerance class, trophic guild, and reproductive group for species collected at 20 sites in the Eastern Highland Rim Ecoregion

[Classifications based on unpublished Tennessee Valley Authority data; *, non-native species; IN, insectivore; TO, tolerant; OM, omnivore; L, Lithophil; HI, headwater intolerant; SP, specialized insectivore; TC, piscivore; HB, herbivore]

Common name	Scientific name	Tolerance class	Trophic guild	Reproductive group
Rock bass	*Ambloplites rupestris*	IN	TC	
Black bullhead	*Ameiurus melas*	TO	OM	
Yellow bullhead	*Ameiurus natalis*	TO	OM	
Freshwater drum	*Aplodinotus grunniens*		IN	
Largescale stoneroller	*Campostoma oligolepis*		OM	
White sucker	*Catostomus commersoni*	TO	OM	L
Rosyside dace	*Clinostomus funduloides*	IN	SP	L
Banded sculpin	*Cottus carolinae*		IN	
Whitetail shiner	*Cyprinella galactura*		IN	
Spotfin shiner	*Cyprinella spiloptera*	TO	IN	
Steelcolor shiner	*Cyprinella whipplei*		IN	
Streamline chub	*Erimystax dissimilis*	IN	SP	L
Creek chubsucker	*Erimyzon oblongus*	IN	IN	L
Chain pickerel	*Esox niger*		TC	
Greenside darter	*Etheostoma blennioides*		SP	L
Slackwater darter	*Etheostoma boschungi*	HI	SP	
Rainbow darter	*Etheostoma caeruleum*		SP	L
Black darter	*Etheostoma duryi*	HI	SP	L
Fantail darter	*Etheostoma flabellare*	IN	SP	
Blueside darter	*Etheostoma jessiae*	IN	SP	L
Stripetail darter	*Etheostoma kennicotti*		SP	L
Blackfin darter	*Etheostoma nigripinne*		SP	
Redline darter	*Etheostoma rufilineatum*		SP	L
Snubnose darter	*Etheostoma simoterum*		SP	L
Spring cavefish	*Forbesichthys agassizi*			
Northern studfish	*Fundulus catenatus*	HI	SP	L
Blackstripe topminnow	*Fundulus notatus*		IN	
Blackspotted topminnow	*Fundulus olivaceus*		IN	
Western mosquitofish	*Gambusia affinis*	TO	IN	
Flame chub	*Hemitremia flammea*		IN	L
Northern hog sucker	*Hypentelium nigricans*	HI	IN	L
Unidentified lamprey	*Ichthyomyzon* sp.			
Channel catfish	*Ictalurus punctatus*		OM	
Brook silverside	*Labidesthes sicculus*		IN	
Least brook lamprey	*Lampetra aepyptera*		HB	
Longnose gar	*Lepisosteus osseus*	TO	TC	

Appendix 4. Fish species, tolerance class, trophic guild, and reproductive group for species collected at 20 sites in the Eastern Highland Rim Ecoregion—Continued

Common name	Scientific name	Tolerance class	Trophic guild	Reproductive group
Redbreast sunfish*	*Lepomis auritus*		IN	
Green sunfish	*Lepomis cyanellus*	TO	IN	
Warmouth	*Lepomis gulosus*		IN	
Bluegill	*Lepomis macrochirus*		IN	
Longear sunfish	*Lepomis megalotis*	HI	IN	
Redear sunfish	*Lepomis microlophus*		IN	
Striped shiner	*Luxilus chrysocephalus*	TO	OM	L
Warpaint shiner	*Luxilus coccogenis*	HI	SP	L
Scarletfin shiner	*Lythrurus fasciolaris*		SP	L
Ribbon shiner	*Lythrurus fumeus*	TO	SP	L
Mountain shiner	*Lythrurus lirus*	HI	SP	L
Spotted sucker	*Minytrema melanops*		IN	L
Black redhorse	*Moxostoma duquesnei*	IN	IN	L
Golden redhorse	*Moxostoma erythrurum*		IN	L
Smallmouth bass	*Micropterus dolomieu*		TC	
Spotted bass	*Micropterus punctulatus*		TC	
Largemouth bass	*Micropterus salmoides*		TC	
Bigeye chub	*Notropis amblops*	HI	SP	L
Bigeye shiner	*Notropis boops*	IN	SP	L
Rosyface shiner	*Notropis rubellus*		SP	L
Telescope shiner	*Notropis telescopus*	IN	SP	L
Mimic shiner	*Notropis volucellus*		SP	L
Slender madtom	*Noturus exilis*	IN	SP	
Rainbow trout*	*Oncorhynchus mykiss*		IN	
Logperch	*Percina caprodes*		SP	L
Dusky darter	*Percina sciera*		SP	L
Bluntnose minnow	*Pimephales notatus*		OM	
Black crappie	*Pomoxis nigromaculatus*		TC	
Blacknose dace	*Rhinichthys atratulus*		IN	L
Creek chub	*Semotilus atromaculatus*	TO	IN	
Sauger	*Stizostedion canadense*		TC	L